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AUSTRALIAN SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

ISSUE 84

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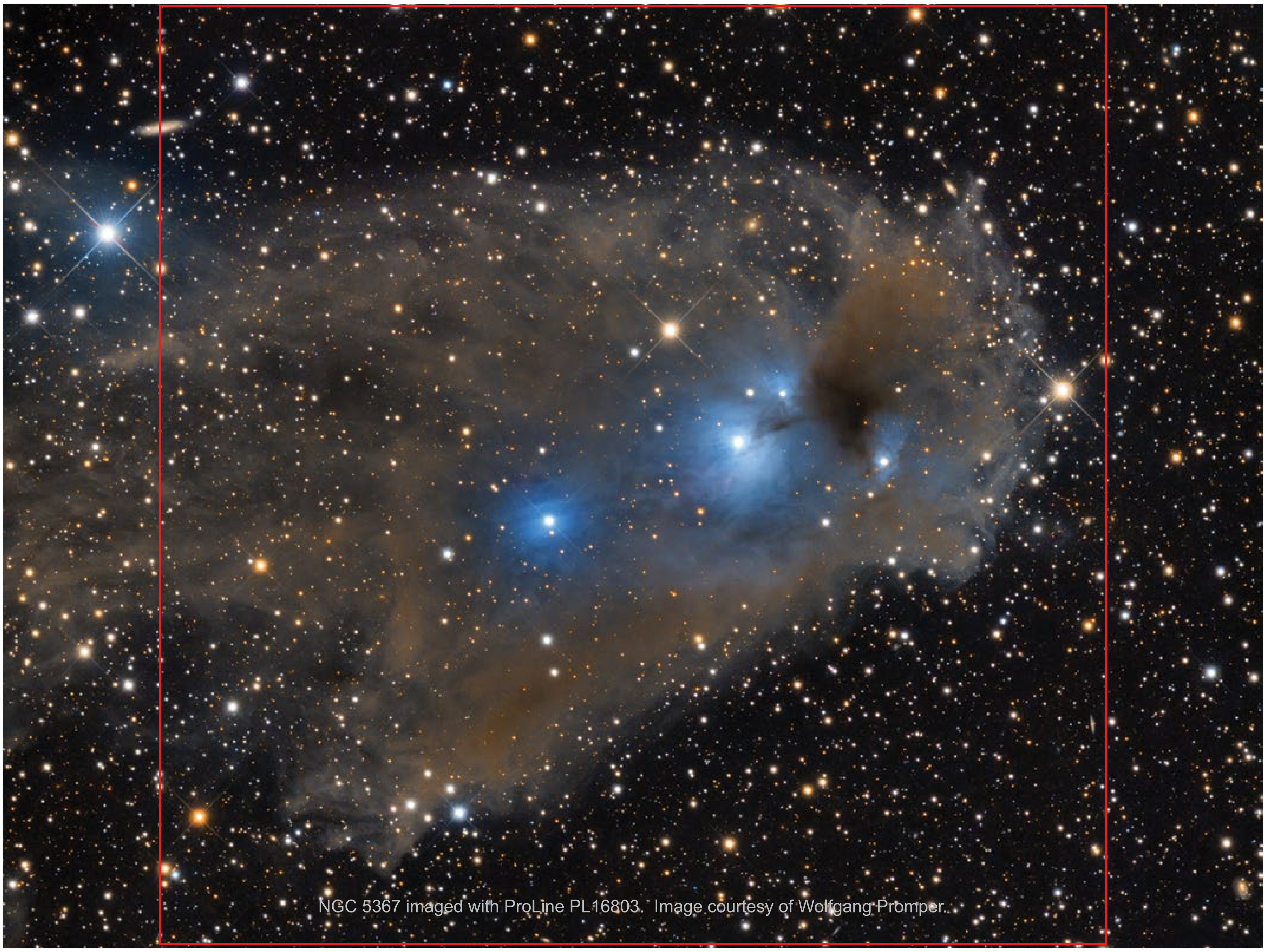

NGC 5367 imaged with ProLine PL16803. Image courtesy of Wolfgang Promper.

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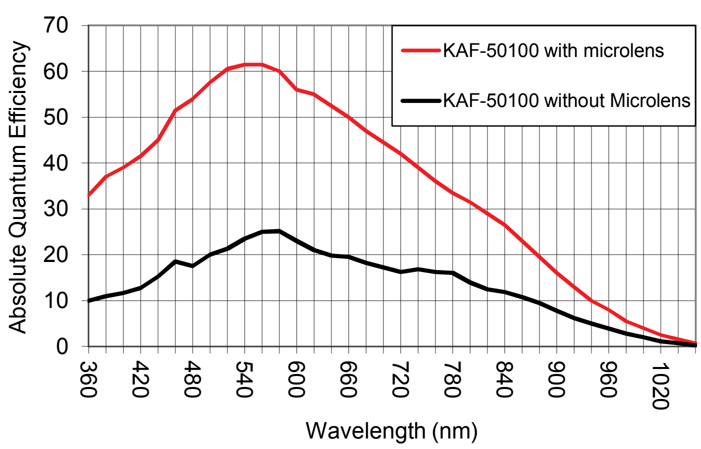

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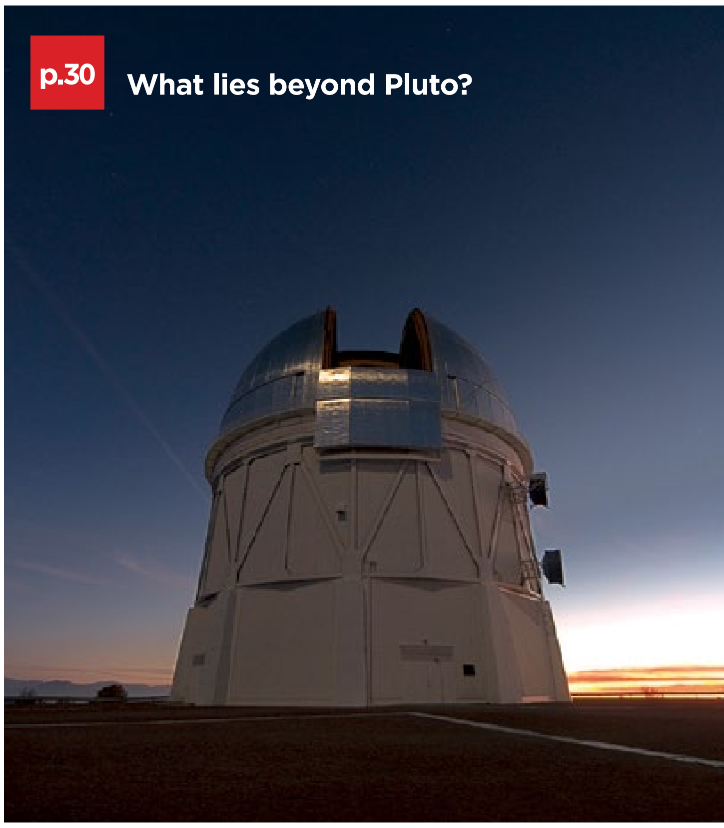
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Jonathan Nally
Spectrum

THE ASTRONOMY SCENE

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ON THE COVER:

Not content with observing Jupiter's four Galilean moons? Try your hand at some of the Solar System's smaller bodies.

AUSTRALIAN SKY & TELESCOPE (ISSN 1832-0457) is published 8 times per year by Odysseus Publishing Pty Limited, PO Box 81, St Leonards, NSW, 1590. Phone (02) 9439 1955, fax (02) 9439 1977.

25 years of scientific service

You know you're getting old when things that were around in your younger years are still around today. I was in my mid-20s when the Hubble Space Telescope was launched in April 1990, and I still remember the excitement that accompanied the event. I also remember the shock and disappointment when it was discovered that the telescope had a flawed primary mirror that produced fuzzy images. And the relief when the first servicing mission fixed that flaw three years later.

Hubble has been around a long time now. A whole generation of young scientists are using it today who weren't even born when it was launched. In fact, two generations have come and gone since the telescope was first proposed at the beginning of the 1970s.

It's almost impossible to single out the most important discoveries it has made during those 25 years, but I'll take a stab with just two.

First, there was the determination of the Hubble Constant, a figure used to help work out the age and size of the Universe. It seems hard to believe now, but back when Hubble was launched, astronomers were still arguing over whether the cosmos was around 7 billion years old or as much as 15 billion. It has now been confirmed using Hubble observations and several other methods, that the universe is 13.7 billion years old, give or take a bit.

And secondly there was the announcement in 1998 that scientists had determined that the expansion of the universe seems to be accelerating over time. Hubble had a lot to do with the observations that led to that result, which was simultaneously worked out by two separate teams and led to the awarding of the Nobel Prize for physics.

As a bit of a tribute to Hubble, in this issue we've included a pictorial spread of just a handful of its famous images. Which ones are your favourites? Some of those we've selected, or perhaps some of the thousands of others the telescope has taken over the years? Drop me a line and let me know.

Jonathan Nally
Editor
editor@skyandtelescope.com.au

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AUSTRALIAN SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY
ISSUE NO 84 APRIL 2015

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ODYSSEUS PUBLISHING

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Printed by Webstar Australia distribution by Network Services. New Zealand distribution by Gordon & Gotch.

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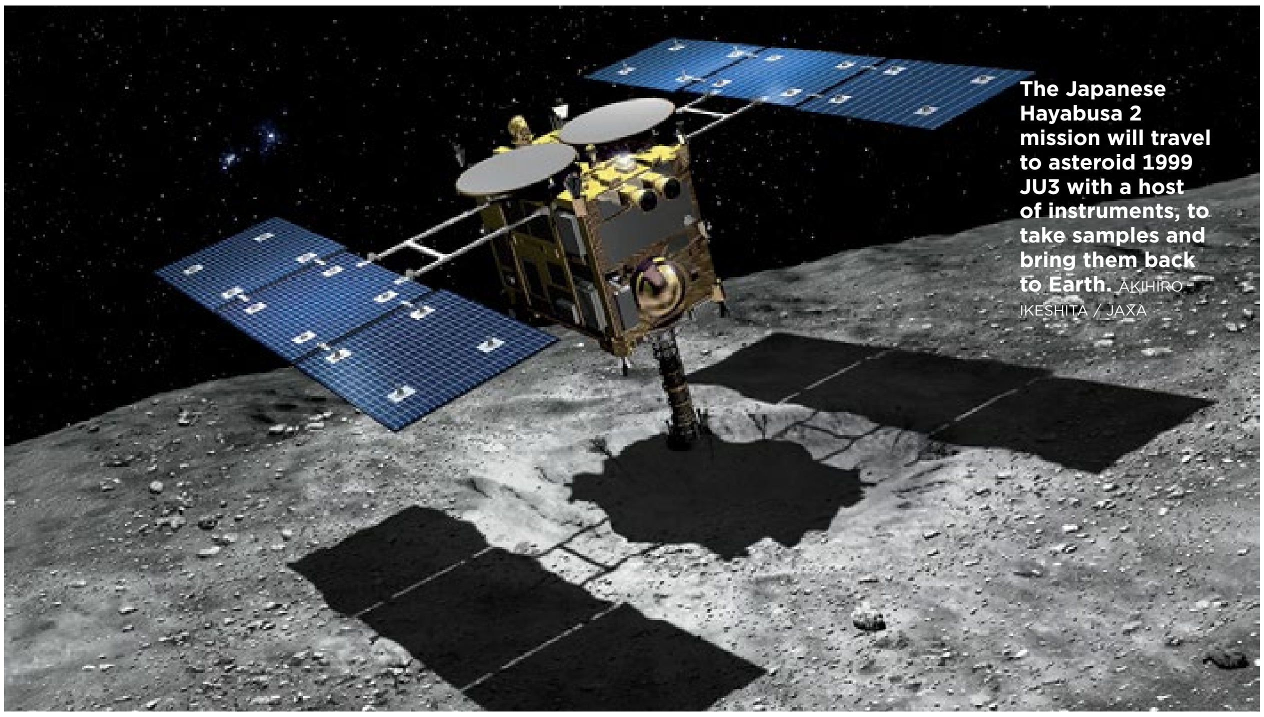
MISSIONS I

Hayabusa 2 Is Asteroid Bound



The Japanese Hayabusa 2 mission will travel to asteroid 1999 JU3 with a host of instruments, to take samples and bring them back to Earth. AKIHIRO IKESHITA / JAXA

On December 3, the Japan Aerospace Exploration Agency (JAXA) launched the spacecraft Hayabusa 2 on an epic journey — to an asteroid and back again. The intrepid explorer will rendezvous with near-Earth asteroid 1999 JU3 in 2018 and obtain samples from its surface before returning to Earth in 2020.

Hayabusa 2 is the successor to the first Hayabusa mission, which is so far the only mission to bring samples of an asteroid back to Earth. Hayabusa 1 limped home with particles from iron-rich 25143 Itokawa in June 2010.

Hayabusa 2's target, 1999 JU3, is an Apollo asteroid roughly 900 metres in diameter with a rotation period of 7½ hours. It generally circles the Sun between the orbits of Earth and Mars and is a C-type, or carbonaceous, asteroid. C-type asteroids are the most common type of asteroid, dark grey, and often seen in the main asteroid belt's outer regions. They are thought to contain significant quantities of water and organic compounds, and many scientists think Earth's water was brought here by similar carbonaceous fragments bombarding our primordial planet. Because asteroids formed early in the evolution of the Solar System and have changed little since then, 1999 JU3 and its kin might hold tantalizing clues from this era.

Similar in design to its predecessor, the main body of Hayabusa 2 is 1 metre × 1.6 metres × 1.4 metres. It weighs in at a total of 600 kg, including fuel. When extended, its solar panels span 6 metres.

One new feature is a speeding bullet: the spacecraft's Small Carry-on Impactor will use an explosive device to shoot a 2-kg copper projectile at the asteroid at a velocity of 2 km/sec (6,400 kph). The spacecraft will deploy a camera to watch the impact (the craft itself will hide behind the asteroid), then return to sample the debris in order to study pristine material from beneath the asteroid's surface.

In addition to taking samples during brief touchdowns in several locations on the asteroid's surface, Hayabusa 2 will also study 1999 JU3 remotely, using its near-infrared spectrometer and thermal infrared imager to examine the temperature variations and mineral composition of the asteroid. Hayabusa 2 will also bring along several traveling companions to make close-up observations: three small Minerva-II rovers (similar to the failed Minerva from Hayabusa 1) and the German Mascot lander.

■ EMILY CONOVER

GALAXIES I Dark Galaxies Discovered in Coma Cluster

A bizarre set of galaxies in the Coma Cluster have lost most of their stellar material, making them especially rich in dark matter.

Pieter van Dokkum (Yale) and colleagues found the galaxies when they took a unique look at Coma through the Dragonfly Telephoto Array, a group of (then) 8 Canon telephoto lenses coupled to CCD cameras on a single mount. The 47 galaxies lurk on the cluster's outskirts and are similar in size to the Milky Way — but with 1/1,000 the number of stars.

To survive in Coma's gravitational turmoil, these dark galaxies must contain 98% dark matter to hold themselves together, much higher than the fraction of matter in the universe at large (83%). Either these weirdly faint galaxies have lost their stars, or they never had many stars in the first place, the team reported on October 29 on the open-access site arXiv.org.

Van Dokkum and colleagues suggest that these may be "failed" galaxies, having forfeited most of their star-building gas after hosting a first generation of stars.

Stars in dwarf galaxies can delay subsequent stellar generations by heating and expelling gas. But simulations also suggest that even normal galaxies start out with three times more star-building material than they use. The energy supernovae dump into their surroundings is one way to limit star formation, says Greg Stinson (Max Planck Institute for Astronomy, Germany).

"I was actually very much relieved to see Prof. van Dokkum's paper," Stinson says. Dark matter simulations have been producing galaxies with exactly the size and matter distribution that van Dokkum's team observed, but such galaxies are naturally difficult to spot.

■ MONICA YOUNG

MISSIONS | Contact Lost with Stereo B Spacecraft

Despite rescue efforts, no one has heard from one of NASA's Stereo (Solar Terrestrial Relations Observatory) spacecraft since October. The Stereo spacecraft circle the Sun in orbits similar to Earth's, with Stereo A ahead of Earth in its orbit and Stereo B behind. The duo thereby watch our star's activity from angles we can't observe. Both craft have currently drifted behind the Sun, meaning that their radio antennas must point near the Sun to communicate with Earth. To protect the equipment from overheating, mission controllers decided to point both craft away from the Sun (and Earth) and to put them in safe-mode hibernation for about a year until they drifted to safety.

Stereo A successfully began its "time out" on August 20. A month later engineers were completing Stereo B's final tests, which involved commanding the craft to go into safe mode and then resume normal operations. But there's been no radio contact with Stereo B since October 1, the day it was supposed to wake up. Its radio signal came in weakly and then quickly faded away.

It appears that the spacecraft suffered a double whammy: first the star tracker could not lock onto its correct guide stars, and then a laser gyro in Stereo B's Inertial Measurement Unit, which senses the craft's orientation, failed and started providing bad data to the attitude-control system. There's now no way to know exactly where Stereo B is pointed or the state of its systems.

Attempts to detect the spacecraft's radio signal using the 100-metre-wide Green Bank Telescope and the 70-metre dishes of NASA's Deep Space Network have thus far failed. According to project scientist Joseph Gurman (NASA Goddard), simulations are under way to deduce the spacecraft's attitude and roll rate based on the few final bits of telemetry received.

All hope is not lost. In 1998, the Solar and Heliospheric Observatory (SOHO) also went AWOL, putting itself in a slow spin with its solar-cell arrays pointed away from the Sun. Eventually, orbital geometry provided enough sunlight (and therefore electricity) to power the craft, and mission controllers regained control. Today, SOHO still provides daily solar images.

■ J. KELLY BEATTY

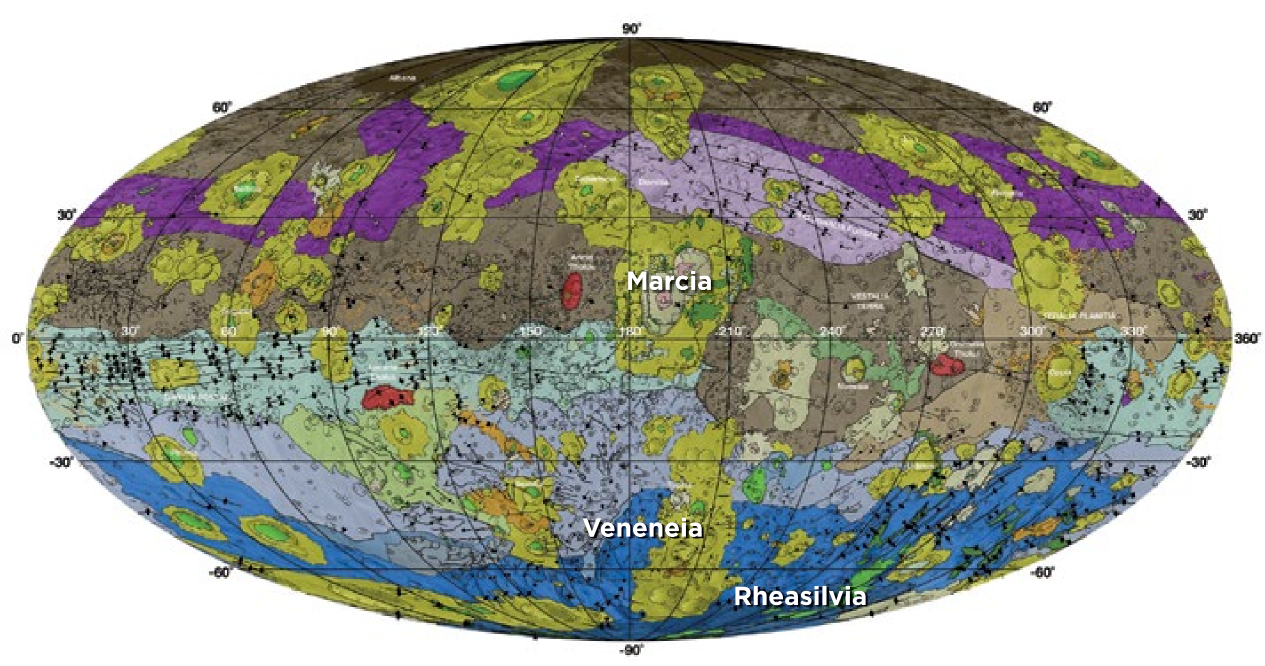
SOLAR SYSTEM | Vesta's Geologic History

Geologists are always seeking to know the sequence of events that shaped a given solid body, and now they have a much better idea of what happened when on asteroid 4 Vesta. A detailed geologic map, a compilation of data from 11 papers in the December issue of *Icarus*, shows features large and small revealed by NASA's Dawn spacecraft during its 14-month-long survey of Vesta in 2011–12. It represents 2½ years of effort by David Williams (Arizona State University) and others.

Shown at right, the global map reveals that this oblong, 573-by-446-km body is divided into provinces pegged to the formation of its three largest craters. Roughly a third of Vesta's surface (shown as brown and tan hues) predates the excavation of 400-km-wide Veneneia basin near Vesta's south pole. A wide northern band (purple) represents terrain emplaced thereafter but before the formation of Rheasilvia, which in size is comparable to the diameter of Vesta itself. Ejecta from that blast are shown in blue hues. A final veneer (greens) followed the formation of 68-km-wide Marcia crater, one of the asteroid's youngest features.

But it's the "when" part of this chronology that's given Williams and his colleagues trouble. They deduce one set of ages when using a model based on the assumed cratering rate within the asteroid belt — and very different ages when attempting to extrapolate from cratering rates on the Moon and from the ages of lunar samples. For example, the Veneneia blast occurred either about 2.1 or 3.7 billion years ago, according to the asteroid or lunar model, respectively. Conversely, Marcia appeared either about 390 (asteroid) or 120 (lunar) million years ago.

■ J. KELLY BEATTY

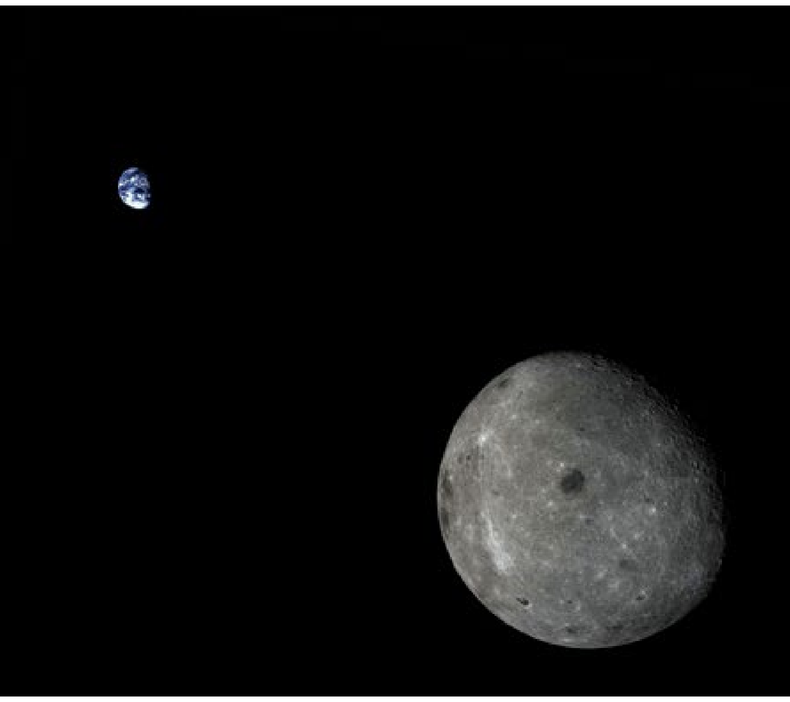


Many geologic terrains mar the surface of Vesta. Black lines with geometric shapes denote different types of linear features, while colours associate features with different major impact events. The canyons around Vesta's equator possibly arose due to stress from the Rheasilvia impact. NASA / JPL-CALTECH / ARIZONA STATE UNIVERSITY

Chinese Chang'e Craft Loops the Moon

An 8-day flight for the Chang'e 5-T1 capsule ended successfully when it parachuted to safety in the Chinese province of Inner Mongolia. Chang'e 5-T1 rode a rocket to space on October 23 and swung around the lunar farside about 13,000 km above the Moon's surface before heading back home. Apart from successfully making the round-trip lunar voyage — the first since the Soviet Union's Luna 24 did so in 1976 — the spacecraft was an engineering test for the upcoming Chang'e 5 sample-return mission. Chang'e 5 is designed to return some 2 kg of lunar material and could take place as early as 2017. This launch only tested reaching the Moon and reentry. It also recorded this view of the Moon (with Earth in the background) on October 28. The small, dark patch near lunar centre is Mare Moscoviense, one of the few lava plains on the Moon's farside.

■ J. KELLY BEATTY



CHINESE NATIONAL SPACE ADMINISTRATION / XINHUANET

IN BRIEF

Eight Billion Oort Asteroids? A fresh look at asteroids moving in comet-like orbits concludes that asteroids must make up about 4% of the Oort Cloud (see page 30). The problem began with the discovery in 1996 of 1996 PW, which had the highly elongated orbit of a comet but looked like an asteroid. Since then, dynamicists have come to suspect that the giant planets' orbits changed dramatically in the early Solar System, flinging small bodies everywhere. Writing in the January 11th *Monthly Notices of the Royal Astronomical Society*, Andrew Shannon (University of Cambridge, UK) and colleagues used computer simulations to confirm that lots of rocky bodies originally within 2½ astronomical units of the Sun should now be lurking among the Oort Cloud's half trillion comets. The estimated 8 billion objects matches an earlier calculation by Paul Weissman (JPL) and Hal Levison (Southwest Research Institute). If true, the Oort Cloud has more asteroids than detected in the main asteroid belt.

■ J. KELLY BEATTY

Evicted Black Hole or Odd Supernova? A weird source of radiation near the dwarf galaxy Markarian 177 might be a supermassive black hole kicked out of the galaxy. The source SDSS J113323.97+550415.8 lies 2,600 light-years from the dwarf's centre and appears in archival observations going back to 1950. Both the object's variability and broad emission lines are typical of a gas-guzzling black hole with a mass of 1 million Suns. But the object's narrow Fe-II emission lines and 2.5-magnitude spike in 2001 better match a *luminous blue variable star* going supernova. Still, the star would have had to experience the largest pre-supernova mass loss ever recorded to explain the decades of above-average brightness, and even then the broad emission lines remain difficult to explain, Michael Koss (University of Hawai'i and ETH Zurich, Switzerland) and colleagues report in the November 21st *Monthly Notices of the Royal Astronomical Society*. Astronomers have found only a few candidate recoiling black holes, which they expect to be created during galaxy mergers.

■ MONICA YOUNG

Community Has Lost a Star

The astronomical community is mourning the passing of Graham Blow on December 31, 2014. He was 60 years old.

Graham had an interest in astronomy from an early age, receiving a 2.5-inch refractor on his 15th birthday. In 1970, he joined the Auckland Astronomical Society, and later the Variable Star Section, and made observations of variable stars using his refractor. He soon became involved in observing total and grazing lunar occultations.

In 1973 Graham assisted in forming the Auckland-based National Junior Coordinating Committee (NJCC) for young astronomers. The NJCC became the National Committee for Student Astronomy in 1974 with Graham as chairman. In 1978 he joined the staff of the Carter Observatory and was scientific officer until it was restructured 17 years later, during this time completing a master's thesis on high-speed recording of occultations.

In October 1977 the Royal Astronomical Society of NZ (RASNZ) Occultation Section was formed, with Graham appointed director – a position he held for 37 years until the time of his death. Graham was elected to the RASNZ council in 1980, variously serving as Vice President, President and Senior Vice President.

One of his greatest achievements was in 1988 when Pluto occulted a 12th-magnitude star. He encouraged observers to observe the event. Seen from Mt John Observatory the star just grazed Pluto's atmosphere, till then unknown. Observers further north saw the star occulted by the planet. These observations contributed to the first accurate determination of Pluto's size.

In 2008 he was elected a fellow of the RASNZ, and in 2013 received the International Occultation Timing Association's Homer F. DaBoll Award. In 2014 he was made an Officer of the New Zealand Order of Merit for services to astronomy. Asteroid 19582 is named in his honour.

Graham's other passion and for many years his profession was photography. He was well known for motorsport and landscape images, and won awards in both fields. ✦

■ JOHN TALBOT AND BRIAN LOADER

PUBLIC ASTRONOMY | Accessible dome officially opened

On January 27, in torrential rain, Sydney Observatory's East Dome was launched by Museum of Applied Arts and Sciences (MAAS) Director Rose Hiscock, President of the Board of Trustees Professor John Shine, and Minister for Disability Services, the Hon John Ajaka MLC.

Despite the rain, 80 guests and media attended the opening, including: eminent astronomer and ground breaking astrophotographer, David Malin; University of Sydney astronomers Professors Anne Green and Elaine Sadler; Astronomer-in-charge of the Australian Astronomical Observatory, Fred Watson; ESA engineer Warrick Holmes; UNSW Professor Michael Burton and University of Western Sydney Assoc. Professor Miroslav Filipovic. Star measurer and computer, Winsome Bellamy, and former Sydney Observatory director Harley Wood's daughter, Ros Madden, were present. Many amateur astronomers and astronomy enthusiasts joined us and all attendees were offered a tour of the facility by the Observatory team.

The project took a decade from inception in 2005 to completion. The East Dome changes the social significance of the observatory site by highlighting the Astrographic Catalogue and the enormity of work achieved by women in that project.

A feature of the project is a state-of-the-art telescope with an articulated eyepiece, which makes viewing of the day and night sky possible for mobility impaired people. Another key achievement has been the restoration and display of a 1890s-era astrographic telescope. The building to house the telescope, which included the reinstallation of a historic copper dome, was designed by the NSW Government Architect's office.

This project has been supported by funds from the Department of Ageing, Home Care and Family and Community Services, Museum of Applied Arts and Sciences (MAAS) Capital Works and the NSW Minister of Finance and Services Monument fund. MAAS Trustee Jim Longley was pivotal in gaining approval to proceed with the project.

Consultant wheelchair astronomer Andrew James at the new telescope (with its extended eyepiece device), along with Minister Ajaka (left) and Geoff Wyatt, education program officer. TONER STEVENSON

10 & 5 Years Ago

April 2005

Black holes shape their surroundings

The huge galaxy Messier 87 (M87) in the constellation Virgo presents us with a fundamental mystery: Why is it so big, yet not much bigger? Understanding the formation of galaxies is one of the great frontiers of modern astrophysics, and giant elliptical galaxies such as M87 present a particularly stark puzzle: something appears to have abruptly halted (and is still preventing) their growth. It seems monster black holes don't just swallow matter without a trace — they sculpt the galaxies and galaxy clusters in which they live.

April 2010

Is there water on the Moon?

The concept was simple: Slam a big enough bullet into a permanently shadowed lunar crater, and the resulting plume of debris should be infused with water vapour that could be detected and measured once it rose into sunlight. Right on schedule the Lunar Crater Observation and Sensing Satellite slammed into the Moon at 2½ kilometres per second. NASA's "crash and splash" gambit dredged up water from a darkened lunar crater — but not nearly as much as scientists expected to find.

Astro Calendar

Snake Valley Astro Camp
March 20-22
Snake Valley, Vic
Phone: 03 5231 3048

WA Astrofest
March 28
Biennial Victorian astronomy conference, hosted in 2015 by the Bendigo Astronomical Society
astronomywa.net.au

VASTROC
April 17-19
Biennial Victorian astronomy conference, hosted in 2015 by the Bendigo Astronomical Society
vastroc.net

RASNZ Conference
May 8-10
Annual meeting of New Zealand's astronomers
rasnz.org.nz/Conference/

Trans-Tasman Symposium on Occultations
May 11
Australasian get-together for occultation observers, this year to be held in Lake Tekapo, NZ
occultations.org.nz

South Pacific Star Party
May 14-17
Annual star party hosted by the Astronomical Society of NSW
asnsw.com/spsp

CWAS Astrofest
July 18-19
Annual conference held in Parkes (home of 'the Dish'), including the David Malin Awards
cwas.org.au/Astrofest/

Queensland Astrofest
August 7-16
Annual star party
qldastrofest.org.au

National Science Week
August 15-23
Lots of public astronomy activities held around Australia
scienceweek.net

WHAT'S GOING ON?
Do you have an event or activity coming up? Email us at editor@skyandtelescope.com.au.

Light at the end of the trajectory

New Horizons begins imaging the Pluto system

Artist's impression of New Horizons swinging past Pluto and Charon, in July 2015. NASA / JHU APL / SWRI / S. GRIBBEN

With only months left to go before encounter day on July 14, the New Horizons mission has begun its 'optical navigation' phase. This is where the craft's own cameras are used to help refine its trajectory by measuring Pluto's position in relation to background stars.

New Horizons is now well into the first of three approach phases (to be matched after encounter day with three departure phases). This phase has included long-range photography of the Pluto-Charon system using the craft's Long-Range Reconnaissance Imager, or LORRI. As New Horizons starts on the final 130 million kilometre run in to Pluto, LORRI will take hundreds of images of the dwarf planet, seeing it grow slowly larger in the field of view each day.

The aim is to work out whether course correction manoeuvres will be needed, the first of which could have been as early as mid-March, around the time this issue of *AS&T* was released. Further opportunities for course corrections will arise as the craft gets closer. Mission controllers want to refine the trajectory to ensure the best possible fly-by while still maintaining a safe distance from Pluto and its five known moons.

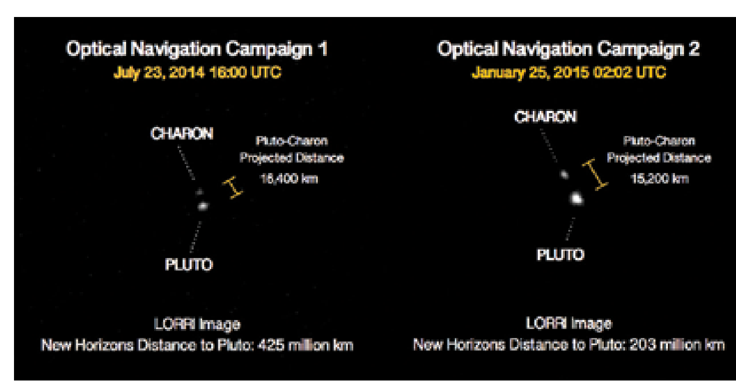
It's also possible that new moons will be spotted on the run-in, and maybe even a thin system of rings. Mission controllers need to keep the craft at a safe distance from those, too, while at the same time formulating a plan to observe them… if they exist.

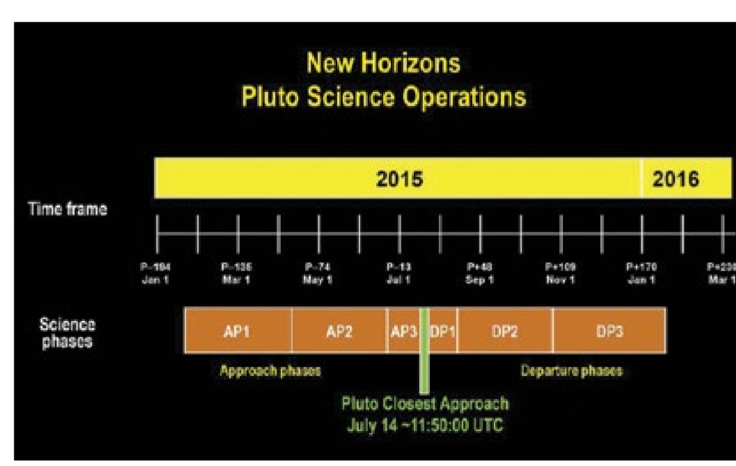
"We need to refine our knowledge of where Pluto will be when New Horizons flies past it," said Mark Holdridge, New Horizons encounter mission manager at the Johns Hopkins University Applied Physics Laboratory. "The flyby timing also has to be exact, because the computer commands that will orient the spacecraft and point the science instruments are based on precisely knowing the time we pass Pluto – which these images will help us determine."

LORRI images taken in late January show a noticeable increase in apparent size of Pluto and its largest moon Charon when compared with images taken in July 2014, during which time the spacecraft halved the distance to its target.

At the same time, New Horizons will continue to be tracked by the big dishes of NASA's Deep Space Network, including those at the Canberra Deep Space Communications Complex at Tidbinbilla, not far from our nation's capital. Timing of the receipt of radio signals from the craft give mission controllers an accurate measure of its distance from Earth. ✦

Below: **In the six months from July 2014 to January 2015, New Horizons halved its distance to Pluto. The dwarf planet and its moon Charon are becoming increasingly larger in images taken with the LORRI camera.** NASA / JHU APL / SWRI





Above: **Timeline showing the approach and departure phases of New Horizons' encounter with Pluto.** NASA / JHU APL

David Ellyard
Discoveries

The riddle of the rings

How a 'triple planet' turned solo

The rings of Saturn are among the wonders of the Solar System. In recent decades, thanks to close-up and long-term observation by space probes such as Cassini, we have come to know their glories in intimate detail. But for centuries they were a puzzle, and we discovered their true nature only in the last hundred years or so. The key discovery has an April date.

Galileo was the first to glimpse the rings more than 400 years ago but his pioneering telescope was too crude to let him see what they actually were. The drawings in his famous book *The Starry Messenger*, published in 1611, show a planet with a bump on either side, like the handles on a bowl.

Galileo hypothesised that his indistinct observations were of a "triple planet", with the three planets almost touching one another, with the largest in the middle being three times the size of those on either side. As was not uncommon at the time, he protected his discovery by announcing it in an anagram written in Latin which, when decoded, said: "I have discovered the most distant planet to have a triple form".

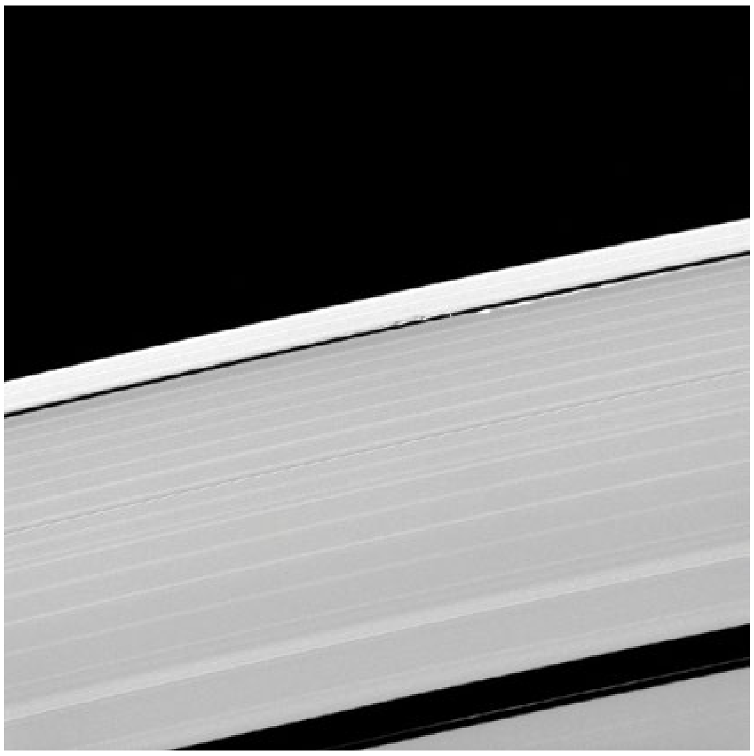
But that was not his only interpretation. At other times he referred to Saturn having "ears" or "arms". To compound the confusion, a year or two after his discovery the bumps on the side disappeared. Galileo reportedly mused as to whether Saturn had "eaten his children", as the mythical Roman god after whom the planet was named had done, according to legend. Then the bumps returned.

The truth slowly emerged. As the century advanced, telescopes improved. Some 35 years after Galileo, the Dutch astronomer Christian Huygens, using a home-made telescope much more powerful than that available to Galileo, suggested that the planet was in reality surrounded by a thin, flat ring, quite separate from the planet itself.

It was the Italian/French astronomer Domenico Cassini who first saw the major division in the ring that bears his name to this day, and glimpsed finer divisions. It now seemed appropriate to talk about "rings" rather than "a ring". Englishman Robert Hooke was able to see shadows cast by the rings on the planet's disc and by the planet on the rings.

But of what were the rings composed? Late in the 18th century, the French mathematician Pierre-Simon Laplace suggested that the whole system was composed of a large number of solid rings. Eight years later the brilliant young Scottish mathematician James Clerk Maxwell, who was later to compose his famous equations on electromagnetism, suggested that solid rings were not feasible. The stresses of rotation and of the pull of Saturn's gravity would shatter them into fragments.

The only alternative suggested that the rings were composed of an immense number of small particles, all orbiting Saturn like tiny moons. It took another 30 years to prove Maxwell right. The key observation took place on April 9, 1895. American astronomer James Keeler, working from an observatory in Pittsburgh, made a series of careful observations of the rings using a spectroscope, which breaks light up into its constituent colours. Motion of the source of the light towards or away from the observer slightly changes the balance of those colours, a consequence of the Doppler Effect. If the source of the light is coming towards the observer, the colour shift is towards the blue; if the motion is away, the light becomes slightly redder. And the amount of colour change is a measure of how fast the source of the light is moving.



The thin, dark gap near the edge of Saturn's rings is named after US astronomer James Keeler. The tiny dot inside the gap is the moon Daphnis. NASA/JPL/SPACE SCIENCE INSTITUTE

Keeler interpreted his observations as showing that the rings are not turning at a uniform speed across their full width, as would be expected if they were solid. Instead he found that the innermost rings were moving faster than those further out, and that the variation in speed matched that required by the Third Law of Planetary Motion, devised by Johannes Kepler at the time of Galileo. This confirmed Maxwell's notion that the rings were essentially swarms of tiny satellites circling Saturn under the influence of its gravity.

We should note that observations similar to Keeler's were made by the Russian astronomer Aristarkh Belopolsky. Indeed, he may have made them first. Such near-simultaneous discoveries are not uncommon in science.

Recent experience with space probes has confirmed that the rings are far from solid. Such probes have passed right through the plane of the rings without hitting anything.

Keeler died from a stroke aged only 42. His name is little remembered now, but he had significant influence in his time. His work with large telescopes advanced the study of nebulae, leading within a few decades to the discovery of external galaxies and the expanding universe. One of the many divisions in the rings of Saturn is named after him, as well as an asteroid and craters on Mars and the Moon. ✦

David Ellyard **presented SkyWatch on ABC TV in the 1980s. His StarWatch StarWheel has sold over 100,000 copies.**

Intergalactic Milestone

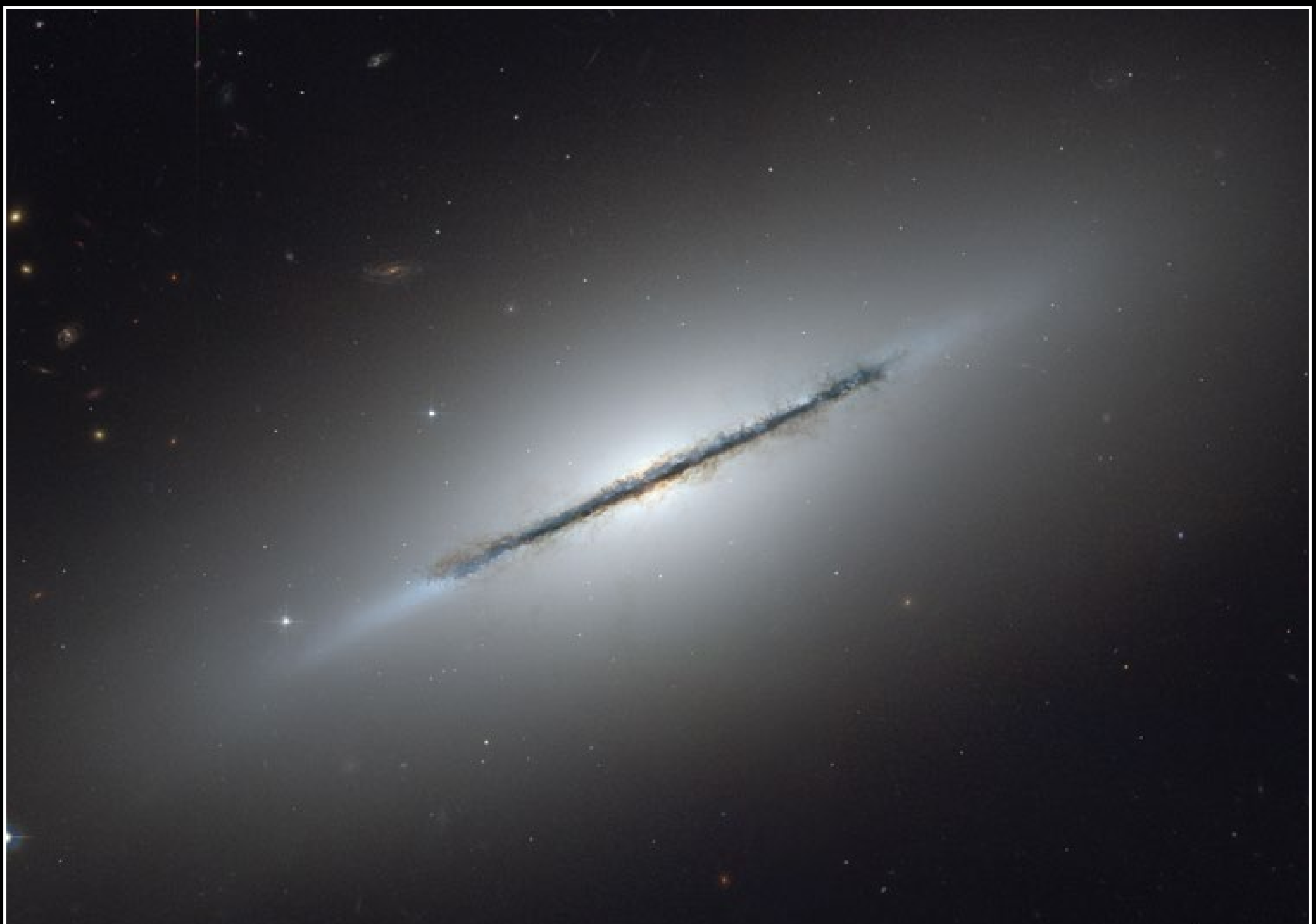
Happy birthday Hubble!

25 years of cosmic discoveries

It seems hard to believe, but the world's most famous telescope was launched into orbit 25 years ago this April. During that quarter of a century it has revolutionised our understanding of the universe… and produced some of the most stunning images ever taken. On these pages we present a handful of its most famous portraits… it's our photographic tribute to the Hubble Space Telescope and the engineers and scientists who made it all happen. ✦

Nicknamed the 'Pillars of Creation', this region of the Eagle Nebula reveals gas and dust clouds that are being tortured by the radiation and stellar winds from young, hot stars.
NASA / ESA / HUBBLE

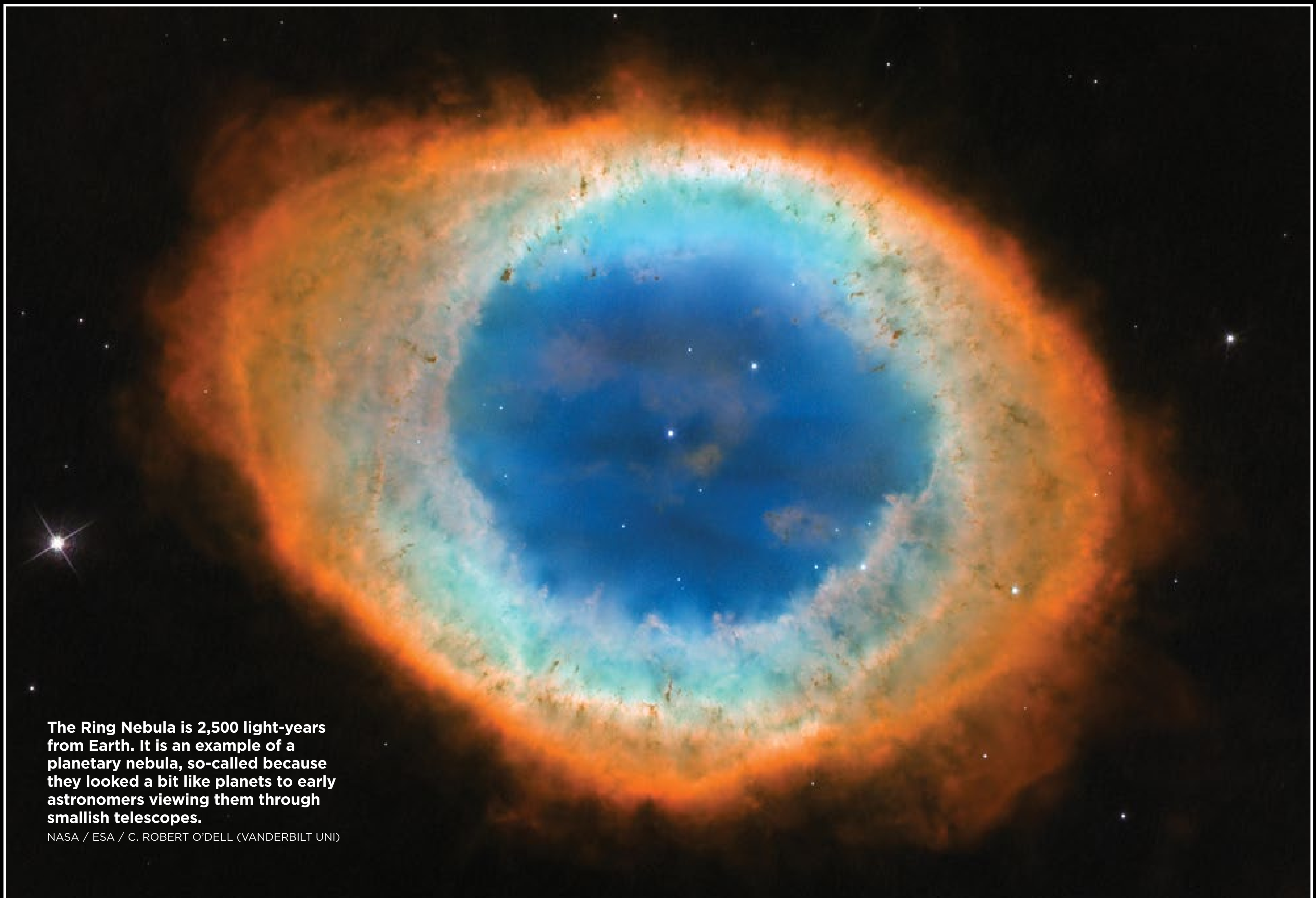
The famous Horsehead Nebula, seen in infrared light. The Horsehead is in the constellation Orion, hanging off the eastern edge of the Hunter's belt.
NASA / ESA / HHT (AURA/STSCI)



Hubble's view of the edge-on galaxy NGC 5866 reveals the thick dust clouds that encircle it.
NASA / ESA / HHT (AURA/STSCI)

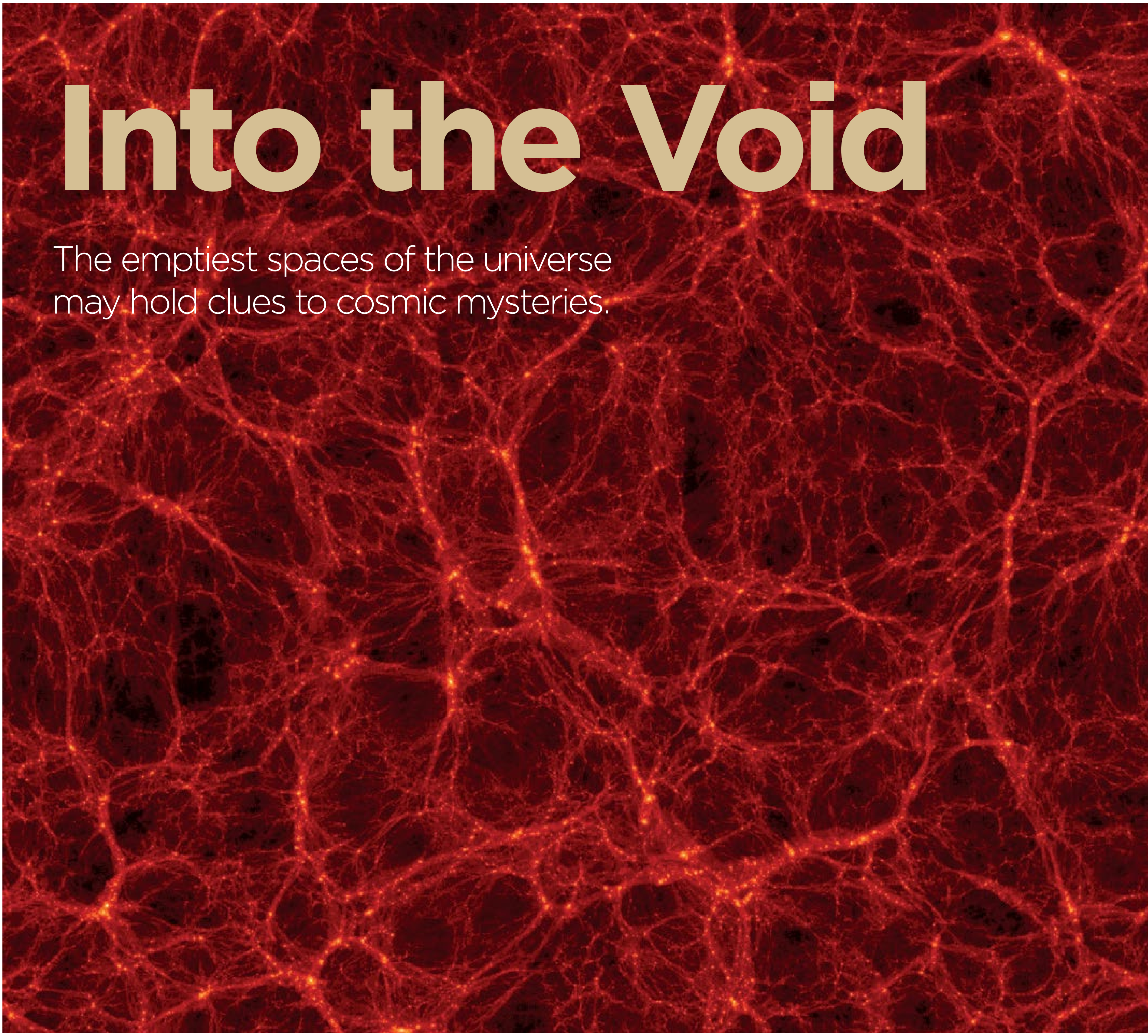
Messier 92 is a globular star cluster that contains more than 300,000 stars, all tightly bunched together. ESA / HUBBLE / NASA / G. CHAPDELAINE

With a low surface brightness, galaxy Messier 74 can be tricky for amateurs to observe. Hubble has no trouble, however, in revealing the spiral arms and pink star-forming regions. NASA / ESA / HUBBLE HERITAGE (STSCI/AURA) ESA/HUBBLE COLLABORATION



The Ring Nebula is 2,500 light-years from Earth. It is an example of a planetary nebula, so-called because they looked a bit like planets to early astronomers viewing them through smallish telescopes.
NASA / ESA / C. ROBERT O'DELL (VANDERBILT UNI)

Dusty clouds are illuminated by the star V838 Monocerotis in a phenomenon known as a 'light echo'. Hubble has been keeping track of changes in the echo over time.
NASA / ESA / HHT (AURA/STSCI)



Into the Void

The emptiest spaces of the universe may hold clues to cosmic mysteries.

Space is pretty empty. And Paul Sutter likes empty. He likes it so much, in fact, that he spends his time exploring the most barren regions of the universe, vast gaps known as cosmic voids.

Almost all the matter in the universe — galaxies and the mysterious, invisible stuff known as dark matter — stretches across space like a giant cobweb. Astronomers call this structure of narrow filaments and thin walls the cosmic web. The vacant expanses in between, akin to the holes inside a sponge, are the voids.

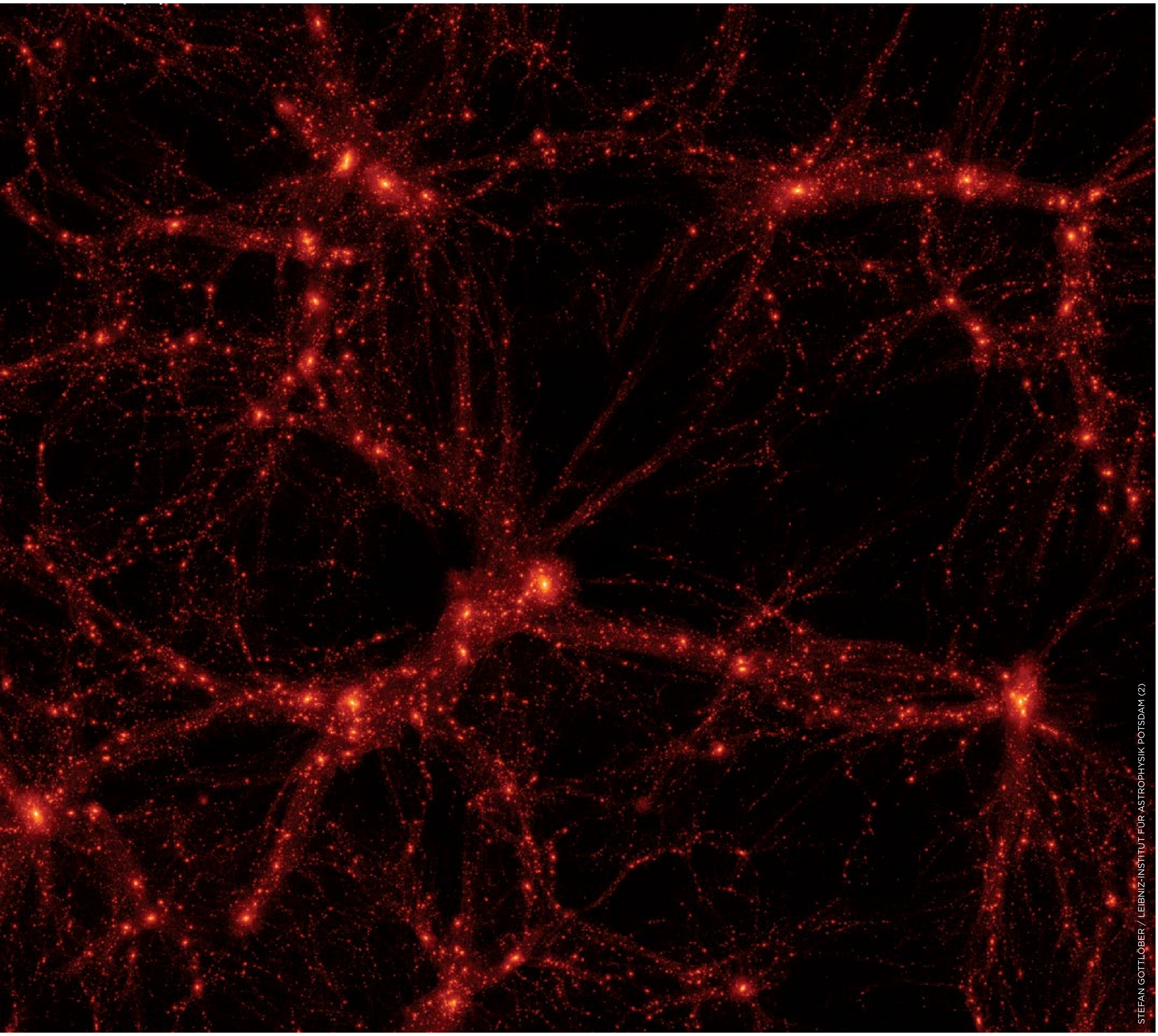
The web varies in density from compact, bustling metropolises, where thousands of galaxies cluster at the intersection of filaments, to calmer suburbs such as our Local Group. But as on Earth, most of the universe is sparsely populated — voids make up about two-thirds of the cosmos by volume. Though not entirely free of galaxies, voids have about a tenth of the universe's average density. And

ROBERT ZIMMERMAN

Sutter feels right at home in this "rural" habitat.

"I'm a rural person myself," says Sutter, who grew up on the outskirts of Lancaster, Ohio, a small town about 50 kilometres southeast of Columbus. "When looking at a map of the cosmic web, most people's eyes are drawn to the bright stuff, the glowing bits. But I'm drawn to the holes, the big empty spaces."

Sutter, now at the Astronomical



STEFAN GOTTLÖBER / LEIBNIZ-INSTITUT FÜR ASTROPHYSIK POTSDAM (2)

UNIVERSE IN A BOX ***Opposite page:*** **Simulations have been modelling the evolution of large-scale structure at ever-increasing resolutions. This slice of the recent Bolshoi simulation is roughly 1 billion light-years across.**

COSMIC WEB ***Above:*** **A zoomed-in slice of the Bolshoi simulation just 300 million light-years across showcases the webby filaments, but the voids are what dominate the simulation's volume.**

Observatory of Trieste, Italy, and Ohio State University, is one of a growing number of astronomers who have been turning their attention toward cosmic voids during the past few years.

Although voids were discovered more than three decades ago, they remained on the periphery of astronomy research for a long time. Recently, dedicated surveys, and the improved technology that made those surveys possible, have exposed the cosmic web's intricacies and unveiled a multitude of voids. Meanwhile, more powerful computers have enabled increasingly detailed simulations of the formation of large-scale structures, such as galaxy clusters and filaments. Combined with a more sophisticated understanding of cosmology, all of this progress has created a field that is just beginning to flourish.

Astronomers such as Sutter are finding that voids are not boring empty

spaces, but rather powerful tools that may help us unravel the mysteries behind dark energy, dark matter, and galaxy evolution. There may be next to nothing inside voids, but there's definitely something to them.

In the Beginning

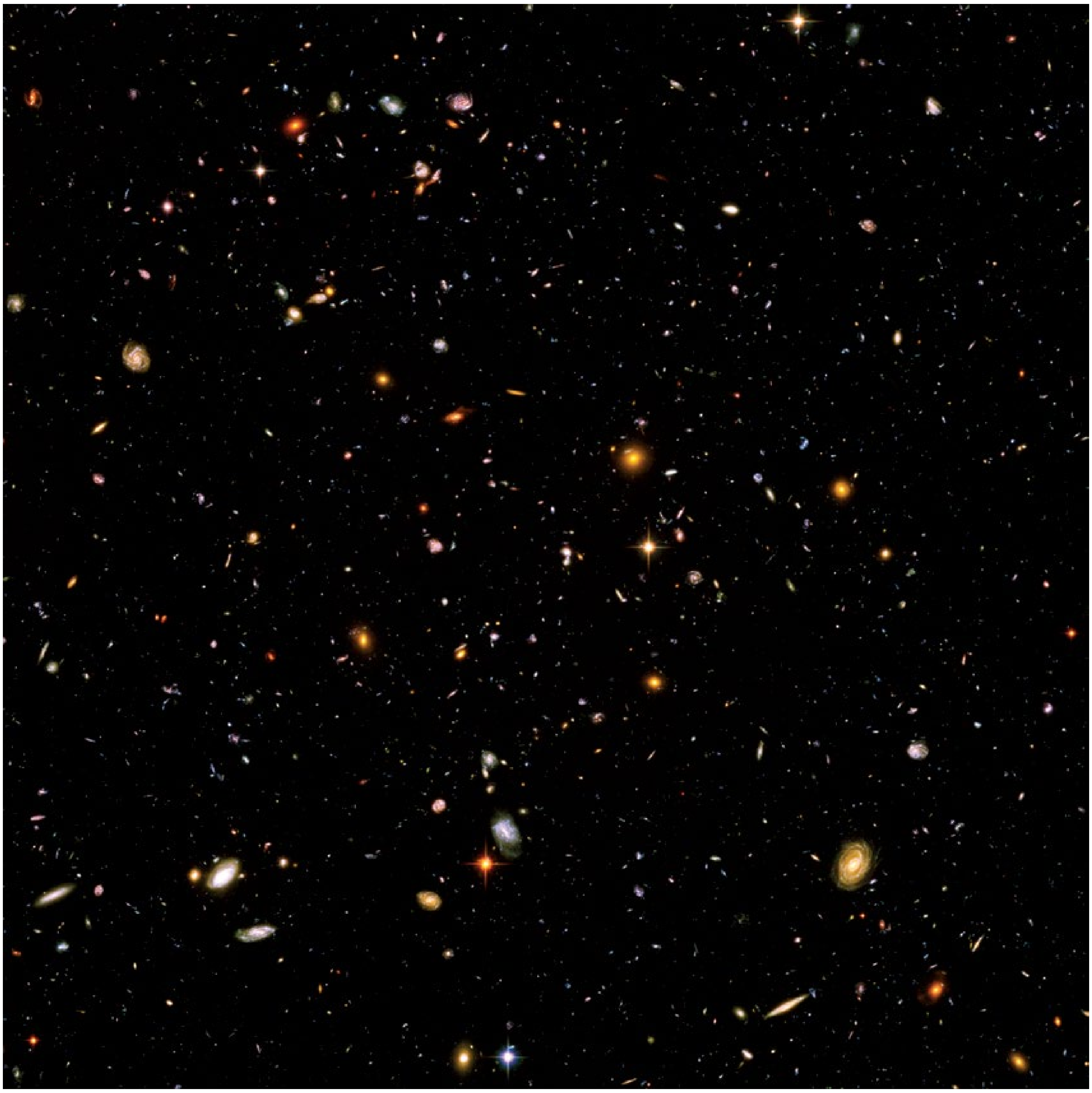
The first voids were discovered in 1978, when Stephen Gregory (then at Bowling Green State University) and Laird Thompson (then at the University of Nebraska) noticed a curiously empty expanse between our own Virgo Supercluster and the Coma Supercluster more than 300 million light-years away. But some astronomers were skeptical — could these gaps just be a trick of the eye?

In 1981, Robert Kirshner (then at the University of Michigan) and his colleagues settled that question when they detected the Boötes void, a gap roughly 300 million light-years across. This was the discovery that convinced astronomers of voids' existence, says Rien van de Weygaert (University of Groningen, The Netherlands).

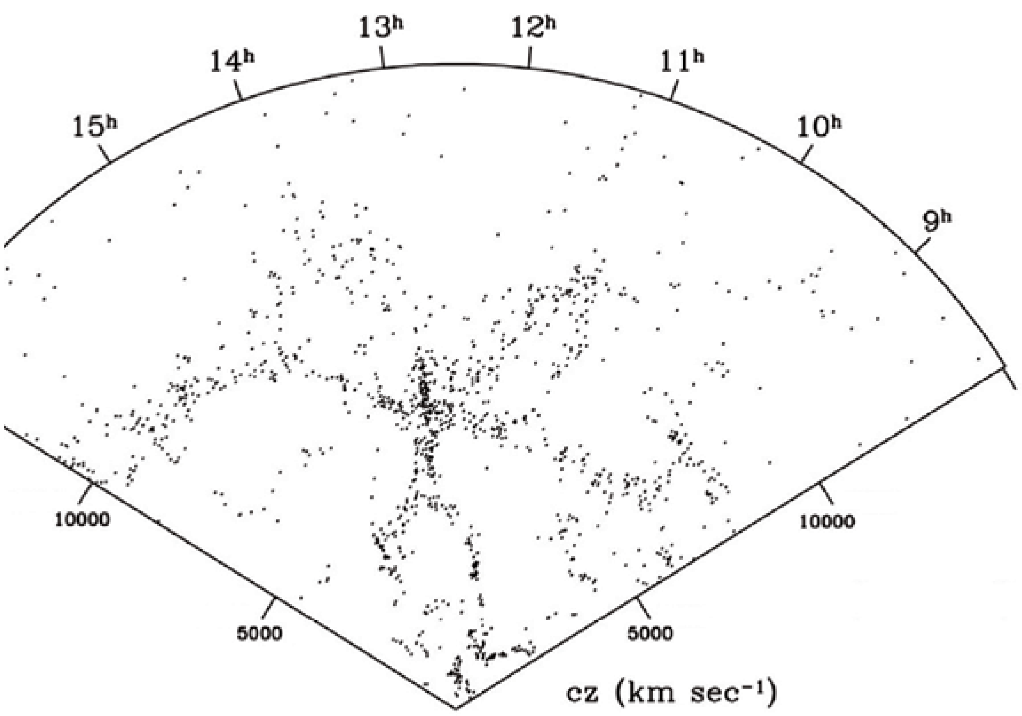
Improvements in detector technology have enabled astronomers to scan the sky for galaxies at ever greater distances, leading to three-dimensional maps of small segments of the universe. In 1986, a team of astronomers based largely at the Harvard-Smithsonian Center for Astrophysics published the first such map. The CfA Redshift Survey revealed a web-like arrangement to the universe, with walls containing more than a thousand galaxies separated by vast empty spaces.

"Voids had been known before, but that image was striking," recalls Michael Vogeley (Drexel University), who was a Harvard undergraduate at the time.

Theorists were making progress, too, modelling the primordial density fluctuations that would eventually grow into the cosmic web. The question became, how did small clumps evolve



PERSPECTIVE The Hubble Ultra Deep Field peers into a narrow cut of the universe; its most distant galaxies live in a universe just 800 million years old. Yet even in an image filled with some 10,000 galaxies, the volume of empty space is apparent. NASA / ESA / STEVE BECKWITH / HUDF TEAM



SMITHSONIAN ASTROPHYSICAL OBS. / V. DE LAPPARENT / M. GELLER / J. HUCHRA

CELESTIAL STICK MAN ***Left:*** **The CfA Redshift Survey mapped 1,100 galaxies to reveal large voids. For example, empty spaces surround the Coma Cluster, where hundreds of galaxies form the famous 'stick man.' Earth is at the apex of this wedge, which extends out to about 700 million light-years. The plot marks distance in redshift units of km/sec.**

into gigantic sheets and filaments? With Cold War tensions still high in the 1980s, the astronomy community formed two opposing camps.

Astronomers in the West subscribed to a so-called bottom-up concept of structure formation. The first galaxies were small, they argued, and lumped together over time to form larger galaxies, clusters and superclusters. The theory predicted a clumpy distribution of galaxies rather than a web with voids — prompting surprise when the CfA Redshift Survey revealed such structure.

Soviet astronomers, on the other hand, held to a top-down idea, in which supercluster-size clouds formed first, then fragmented into galaxies. But even though the Soviets' concept correctly predicted a cosmic web, it also predicted (among other things) young, recently formed galaxies, a conclusion not upheld by observations.

After the Soviet Union broke up, astronomers from both sides began to share ideas, van de Weygaert says. "In the end, you get a synergy and you get a new theory and a new view." By the 1990s, the bottom-up scenario had won out, but with theoretical improvements (including the addition of cold dark matter) that recreated the observed cosmic web.

These developments coincided with advances in computer simulations. Astronomers tried to simulate structure formation as early as the 1970s but were only able to follow the motions of at most a thousand or so particles. In the 1980s, simulations with hundreds of thousands of particles were able to form filaments, clusters, and voids. Nowadays, simulations involve 10 billion particles and are capable of modeling not only dark matter but also the evolution within galaxies. "Because of the enormous increase in computer power, we're talking about a completely different order-of-magnitude view of how structure forms," van de Weygaert says.

Nothing to See Here

The earliest galaxy surveys unveiled only a handful of voids, easily picked out by eye, but that number continues to grow.

"As time has gone on, some large surveys and more careful work have revealed that these voids essentially fill the universe," Vogeley says. "They're ubiquitous and perhaps the most important feature of large-scale structure."

As surveys have grown, astronomers needed a systematic way to define and identify voids. For a while, van de Weygaert says, devising these kinds of search algorithms became one of the main challenges of the field. How do you determine a

GALAXIES IN ISOLATION

Despite what the name implies, voids aren't completely empty. The Boötes void, for example, contains 60 known galaxies in a region about 300 million light-years across. For comparison, the Local Group — of which the Milky Way is a member — has roughly the same number of galaxies squeezed into a space just 10 million light-years across.

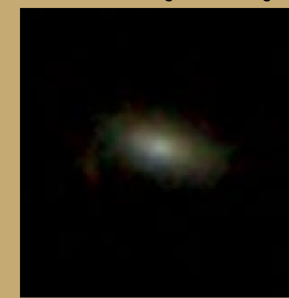
Roughly speaking, voids have 10 times fewer galaxies per volume than the cosmic average, and 1,000 times fewer galaxies per volume than a galaxy cluster, Vogeley says.

Void galaxies are unique because they form and evolve in such a desolate environment. Galaxies in groups tend to collide, whether in glancing interactions or in full-on mergers; both serve to disrupt their gas and produce stellar baby booms. In crowded cluster environments, a hot gas halo may complicate collisions further by stripping gas from galaxies that are passing through, stopping star formation in its tracks.

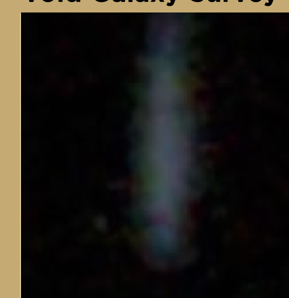
Far from the influence of other galaxies and their hot gas halos, evolution instead depends on primordial gas flowing in along cosmological filaments. As a result, voids serve as pristine laboratories, where galaxies evolve much more slowly and simply.

Surveys of nearby void galaxies have found that most are faint and blue — in other words, small spiral galaxies. Due to their shorter evolutionary history, these galactic runts are still forming lots of new stars for their size compared to similar galaxies in nearby groups, which have largely ceased significant amounts of star formation.

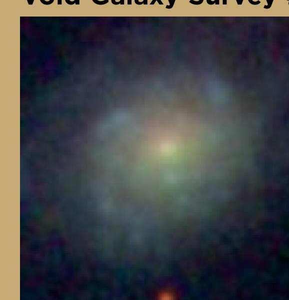
Void Galaxy Survey #1



Void Galaxy Survey #30



Void Galaxy Survey #32



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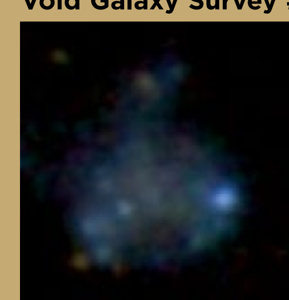

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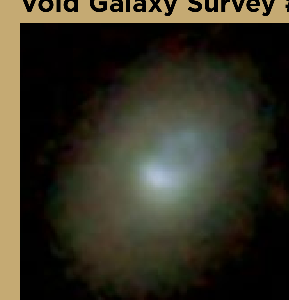
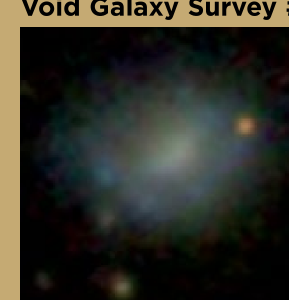
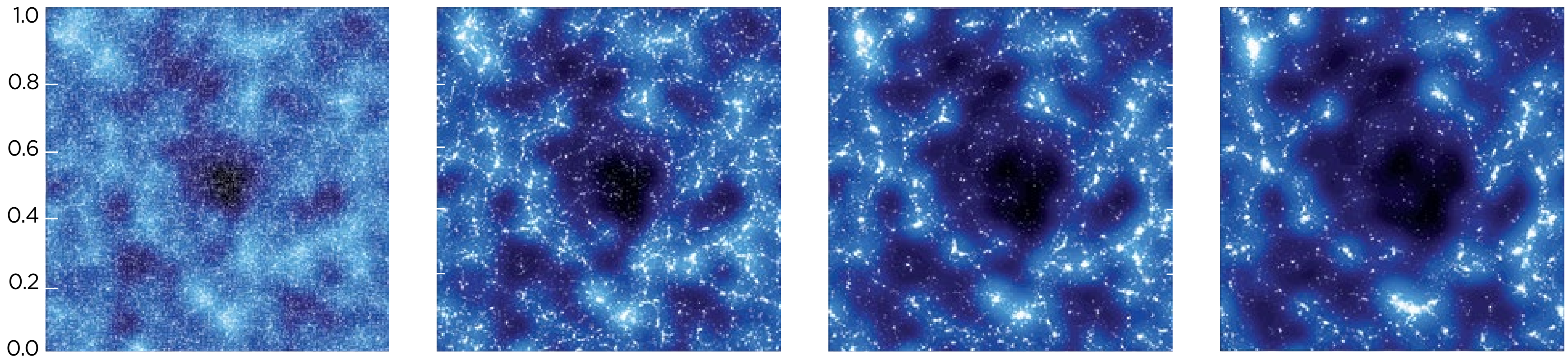


Void Galaxy Survey #58



DESERTED GALAXIES ***Right*****: Six examples from the Void Galaxy Survey show a youthful appearance. Galaxies reared in relative isolation tend to be fainter and bluer, with high star formation rates for their masses.**

SDSS, SOURCE: KRECKEL ET AL. 2011



GROWING A VOID In these simulation frames, matter streams out from the center of a void to collect along its edges. The simulation box is more than 200 million light-years on a side, and about 50 million light-years thick. ERWIN PLATEN (4)

void's boundaries? What's considered a void and what's just a less-dense part of space?

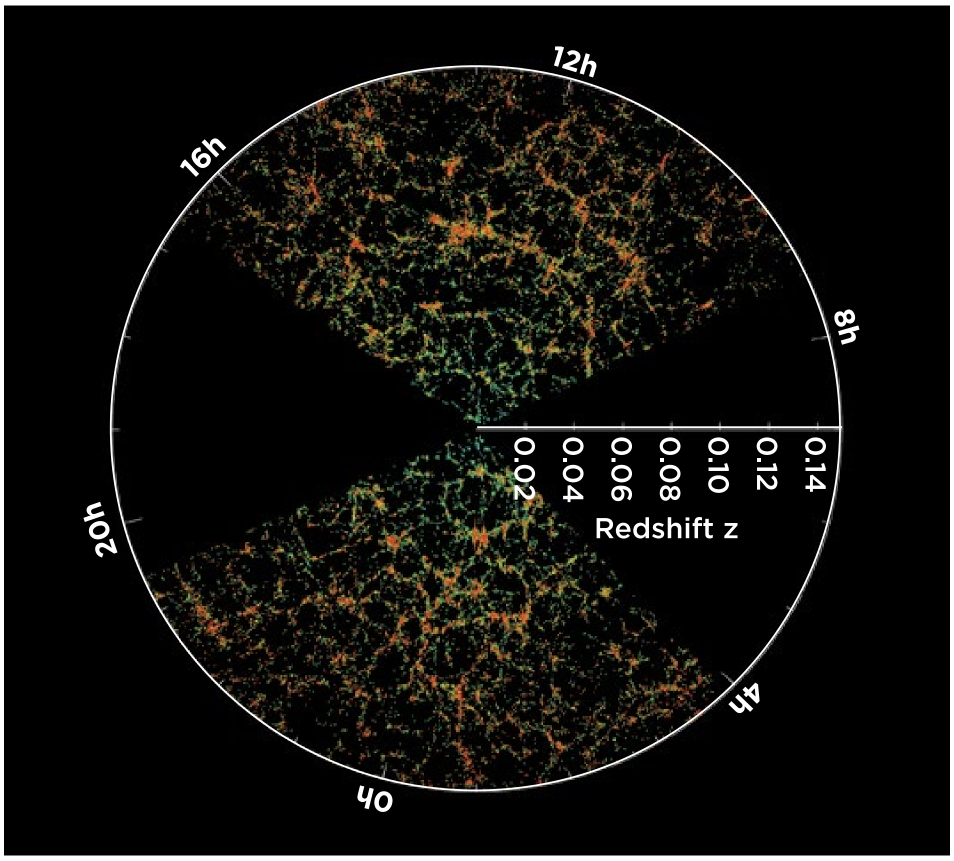
Vogeley and his colleagues, for instance, have used an algorithm that spots sparser regions of space by calculating the distance to each galaxy's nearest neighbours. In 2004 Vogeley and Fiona Hoyle (now at Widener University) used this algorithm to find 289 voids in the Two-degree-Field Galaxy Redshift Survey, which contains more than 245,000 galaxies. Then in 2012, Vogeley, Hoyle, and others sifted through 700,000 galaxies in the Sloan Digital Sky Survey, the biggest three-dimensional map of the universe, to find 1,054 voids.

In the past few years, however, another algorithm called the watershed method has gained traction, van de Weygaert says. Originally an image-processing technique, the watershed algorithm transforms the cosmic web into a topographical map. Dense galaxy clusters become mountain peaks, smaller groups become foothills, and emptier regions turn into lowlands. If you filled this landscape with water, it would collect in deep basins — the voids — whose boundaries are defined by the ridges surrounding them. Using this technique on Sloan data, Sutter and colleagues have built a catalogue of more than 2,000 cosmic voids so far.

If voids will ever help us glean deeper insight into the universe, finding more of them is essential. "With thousands of things," Sutter explains, "you can start doing statistics, you can start doing comparisons, you can start doing some pretty serious science."

One void might boast a strange shape or contain a couple of odd galaxies, he adds, but on average, voids have surprisingly regular features. For example, Nico Hamaus (Sorbonne University, France) recently led a team including Sutter that analysed computer-simulated voids. They found that the relationship between a void's density and its size obeys a simple universal law.

Although voids are important in their own right as part of the structure of the universe, what's really stirring excitement is something more tantalising. Astronomers are realising that voids could help untangle the nature of dark energy, the unknown force that's driving the acceleration of the universe's expansion.



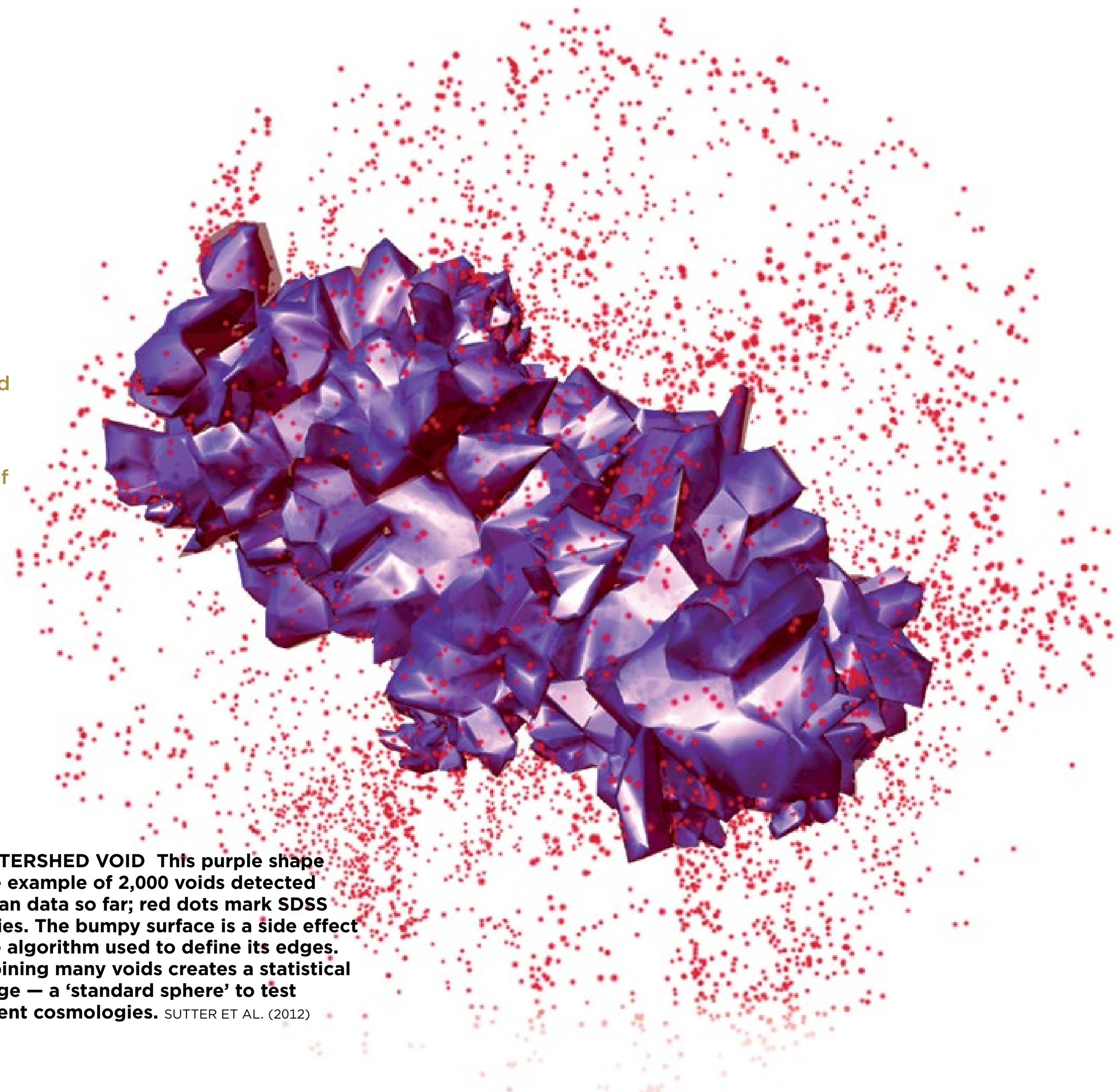
Mapping the universe Every dot is a galaxy in this slice through SDSS data. Redder points tend to be galaxies with older stars. The survey has vastly expanded astronomers' view of the cosmic web — and the voids contained within. MICHAEL BLANTON / SDSS

Pristine Laboratories

Dark energy dominates within voids due to minimal gravitational influence from galaxies and dark matter. So voids act as natural laboratories to explore this weird anti-gravitational force.

Voids expand more quickly than denser regions of the universe even without the effects of dark energy. Since more mass surrounds a void than exists inside it, inner matter will stream toward the edge under gravity's influence to push on the void's inner walls. Individual voids may have a blob-like asymmetry, with certain parts expanding faster than others, but combine enough voids and you can generate a statistical average, a 'standard sphere.' This generic void expands over cosmic time in a predictable way.

DARK MATTER VS. DARK ENERGY
Though the names are similar, dark matter and dark energy are opposite in concept: dark matter attracts and dark energy repels. Dark matter holds roughly 27% of the universe's energy. It doesn't emit or absorb light, making it all but impossible to detect except by its gravitational effects. Dark energy, on the other hand, is thought to be a negative force that pervades the entire cosmos and accelerates cosmic expansion. It's the dominant form of energy in the universe, making up 68% of the total energy budget. That leaves less than 5% of the universe's total energy in normal matter.



A WATERSHED VOID This purple shape is one example of 2,000 voids detected in Sloan data so far; red dots mark SDSS galaxies. The bumpy surface is a side effect of the algorithm used to define its edges. Combining many voids creates a statistical average — a 'standard sphere' to test different cosmologies. SUTTER ET AL. (2012)

Dark energy changes that equation. By assessing the shapes of 1,500 voids found in the Sloan data in 2014, Sutter and colleagues measured what fraction of the universe's energy comes in the form of dark energy. Although their answer currently lacks competitive precision, with bigger void samples they expect to measure the fraction of dark energy as well as, if not better than, other, independent methods.

And this technique is only one way voids can help astronomers untangle the universe's mysteries. The precise amounts of dark matter and dark energy set the initial conditions of the cosmos and determine the evolution of voids and the rest of large-scale structure. So despite their lack of matter, voids' role in large-scale structure can help pin down how much dark matter exists and how it interacts with the rest of the universe.

As with dark energy, it's a void's emptiness that's useful for studying dark matter, Sutter says. Voids are simple places, free from the complicated physics of crowded galaxy clusters where dark matter is traditionally studied. So any influence from dark matter edging the void can easily be isolated.

"Inside a void, life is simple," Sutter adds. "You get out of the cities and get in the rural areas, and it's just corn. And you can model corn a lot more easily than you can model a city."

Voids may help peg the exact fractions of dark matter and dark energy in the leading cosmological model, or they could be used to test alternate theories. Some astronomers have speculated that dark matter and dark energy aren't actually exotic new entities; they could instead be explained by modifying our law of gravity. One such model predicts more large voids, a difference that is potentially measurable given a big enough void sample and a strong enough modification to gravity.

The study of voids adds to a long list of well-established cosmology techniques. Astronomers currently determine cosmic expansion by measuring the brightness of standard candles known as Type Ia supernovae. They can also gauge distances via the standard ruler of baryon acoustic oscillations, the echo of primordial density fluctuations seen in today's web of galaxies. Astronomers can test the growth of large-scale structure by comparing galaxy clusters near and far. And, of course, one of the best methods of estimating cosmological parameters is to model the temperature fluctuations in the cosmic microwave background, the Big Bang's remnant radiation.

According to some astronomers, voids could turn out to surpass all of these cosmological probes, van de Weygaert says. But he remains cautious: "I hope it's true, but I'm not entirely convinced."

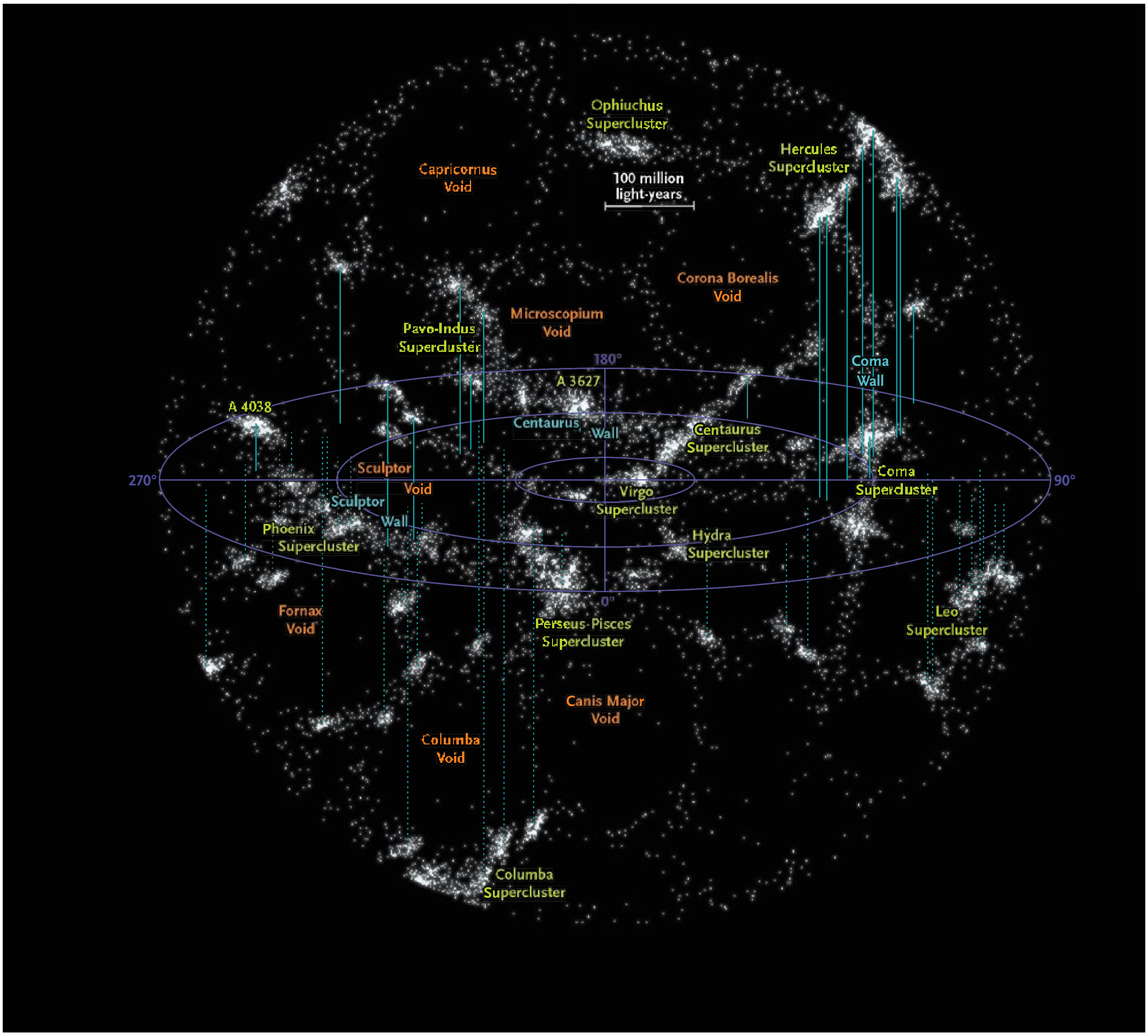
The key, Sutter and Vogeley argue, is more voids.

Night Skies in the Void

Even inside a void, an extraterrestrial's night sky wouldn't look that different from our own — most of the celestial objects we see, after all, are stars within our own galaxy. In fact, a void galaxy would have a higher star formation rate for its size than the Milky Way, so star-forming features such as the Orion Nebula might be more prevalent.

But peering through a telescope would probably not show any other luminous galaxies for many millions of light-years. Vogeley estimates that galaxies in a typical void are an average million fifty light-years apart, twice the average distance between galaxies in the Local Group, and ten times the distance between galaxies in a typical cluster. So there would be no nearby Andromeda Galaxy, and no nearby Virgo Cluster. Any void-living aliens might have a far different understanding of cosmology. Still, if their technology advanced to the point of seeing beyond the void's edge, an alien's map of large-scale structures would begin to show a universe statistically similar to ours.

— Monica Young



Toward a Million Voids

The case for voids as a powerful cosmological probe has only come close to reality as observational datasets have expanded in the past few years.

"We're really just scratching the surface," Vogeley says of recent work. "People only now are getting their hands dirty on actual data."

"We're right at the edge," Sutter adds, "at the stage where we're proving that it works, that it's not crazy."

In coming years, the Sloan survey will continue to provide larger galaxy

OUR NEIGHBOURHOOD This simplified map shows clusters and voids within 500 million light-years of the Milky Way. Some galaxies were removed to clarify this two-dimensional representation. The supergalactic coordinates are based on the plane of the Virgo Supercluster. S&T: GREGG DINDERMAN, SOURCE: RICHARD POWELL / WWW.ATLASOFTHEUNIVERSE.COM

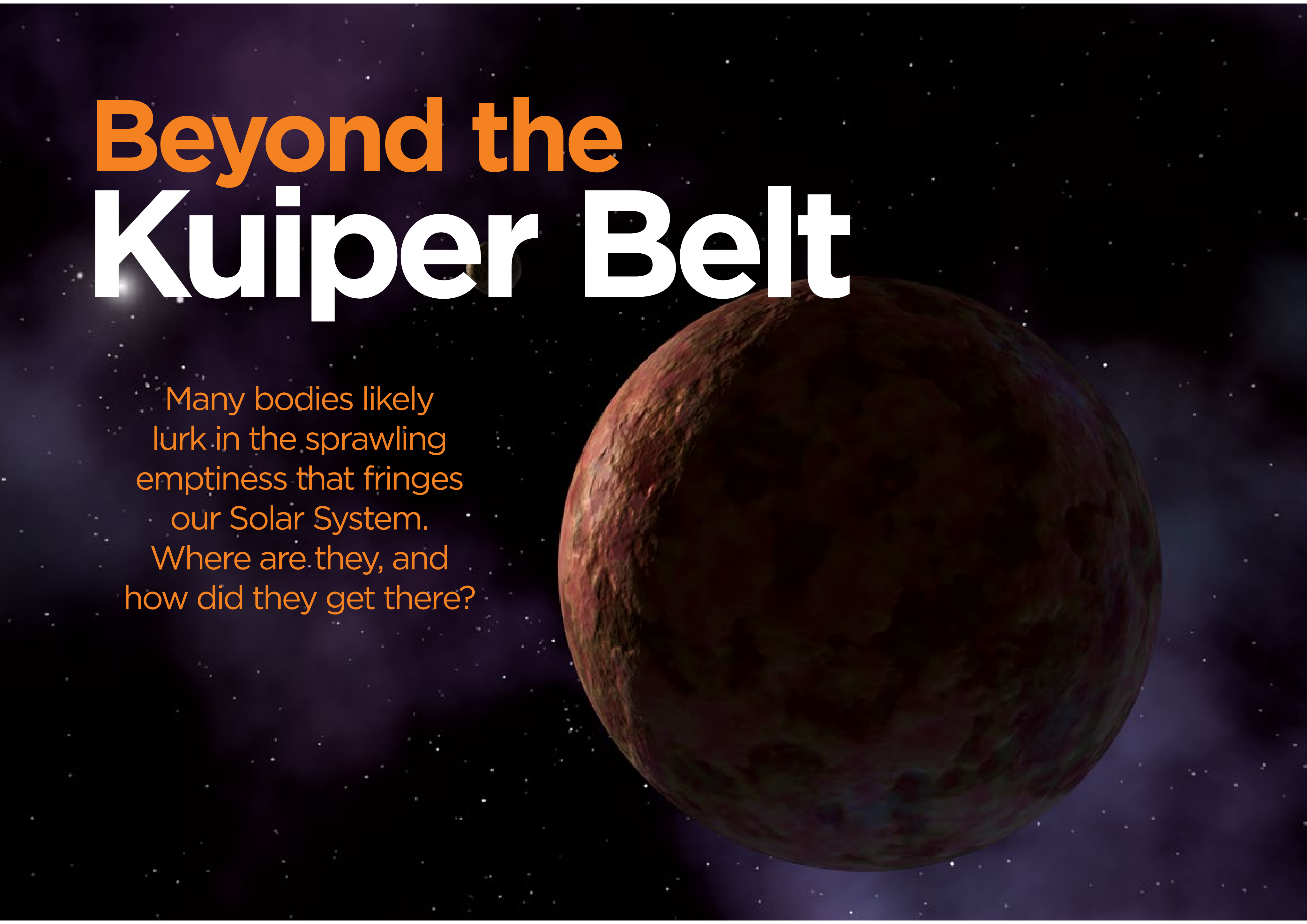
maps — and more voids. But the study of voids won't realise its full potential until the next generation of telescopes and associated surveys help push the void count to a million. The European Space Agency's Euclid spacecraft, scheduled for launch in 2020, will survey galaxies in a universe just 3 billion years old. NASA's planned Wide-Field Infrared Survey Telescope could deliver a similar map. And the planned Large Synoptic Survey Telescope and Square Kilometre Array will also provide a glut of galaxy data.

The study of voids is a burgeoning field, and Sutter's mission is to continue spreading the word. As he says, "Voids are awesome and voids are the future." ✦

***Marcus Woo*, formerly a freelance science writer, now writes for *Wired* magazine.**

Beyond the Kuiper Belt

Many bodies likely lurk in the sprawling emptiness that fringes our Solar System. Where are they, and how did they get there?



DISTANT ENIGMA Sedna (above, in an artist's conception) was discovered in 2003 far beyond Pluto and the classical Kuiper Belt. Do other large bodies like Sedna exist in the far reaches of our Solar System? Astronomers are avidly searching for them.

SCOTT S. SHEPPARD

In 1781 William Herschel discovered Uranus, the first planet not easily observable with the naked eye. Astronomers found Uranus' orbit to be peculiar, as if a more distant planet's gravity pulled on it. A search for this unseen planet led to the discovery of Neptune in 1846. Neptune's motion was also thought to be peculiar, which led to the discovery of Pluto in 1930.

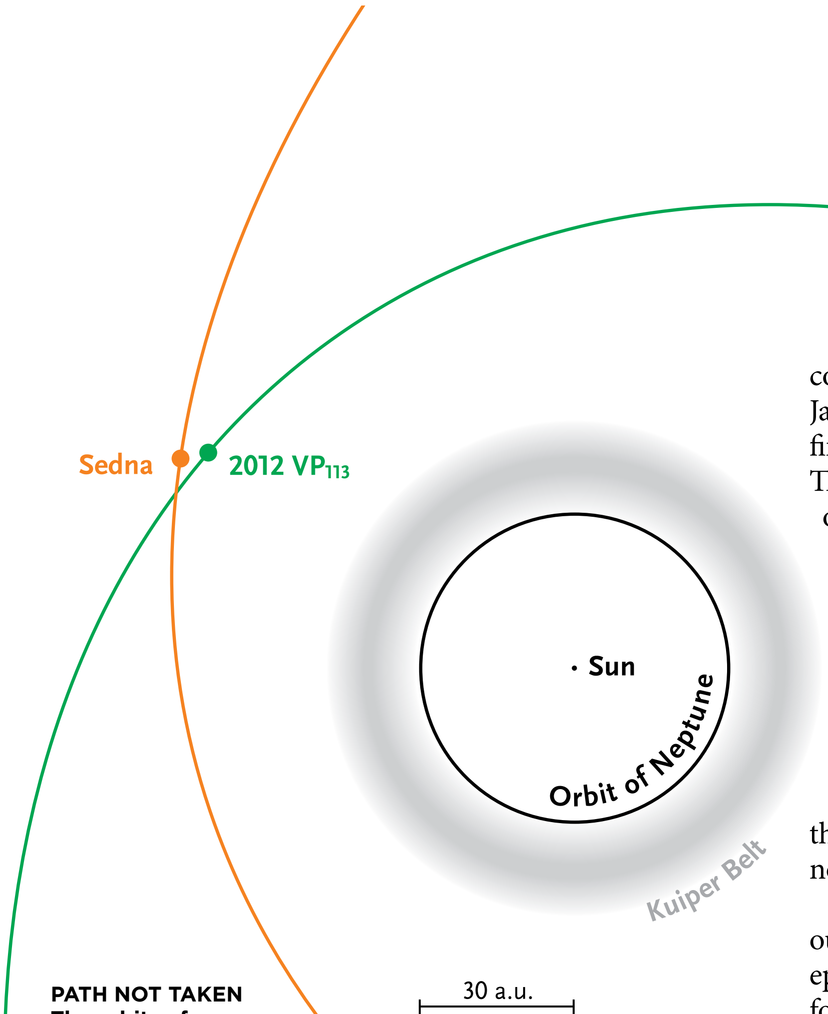
But astronomers have now determined that Pluto is only about 2,322 kilometres in size, which is smaller than Earth's Moon, and not massive enough to affect Neptune's orbit. Later observations revealed that Neptune's motion was as expected, and no massive perturber was called for.

Our exploration of the outer Solar System was just beginning, however, and it continues today, with new discoveries and new mysteries arising all the time. Beyond Neptune lies an expanse of icy bodies, only a relative handful of which we've detected. And we're still figuring out how these mini worlds wound up where they are today.

The Kuiper and the Oort

Some 2,000 objects are known to orbit at distances from the Sun similar to Pluto, a region now called the Kuiper Belt. The Kuiper Belt appears to have an edge around 48 astronomical units, or 48 times the Sun-Earth distance, at which point the number of objects falls off sharply. The Kuiper Belt is a remnant of the original solar nebula out of which our planetary system formed, but it is made of the material that couldn't coalesce into a planet due to the large volume of space and low density of matter so far from the Sun. In fact, it is so hard to form objects in the outer Solar System that Uranus and Neptune likely didn't form where they are now but were pushed out through gravitational interactions with Jupiter and Saturn.

Short-period comets, whose orbits are not much inclined to the plane of the planets and reach out to only a few to tens of a.u. from the Sun, are likely recent escapees from the Kuiper Belt.



PATH NOT TAKEN The orbits of Sedna and 2012 VP113 lie entirely outside of Neptune's. But their highly elliptical orbits mean they came close to and gravitationally interacted with *something* in the past.

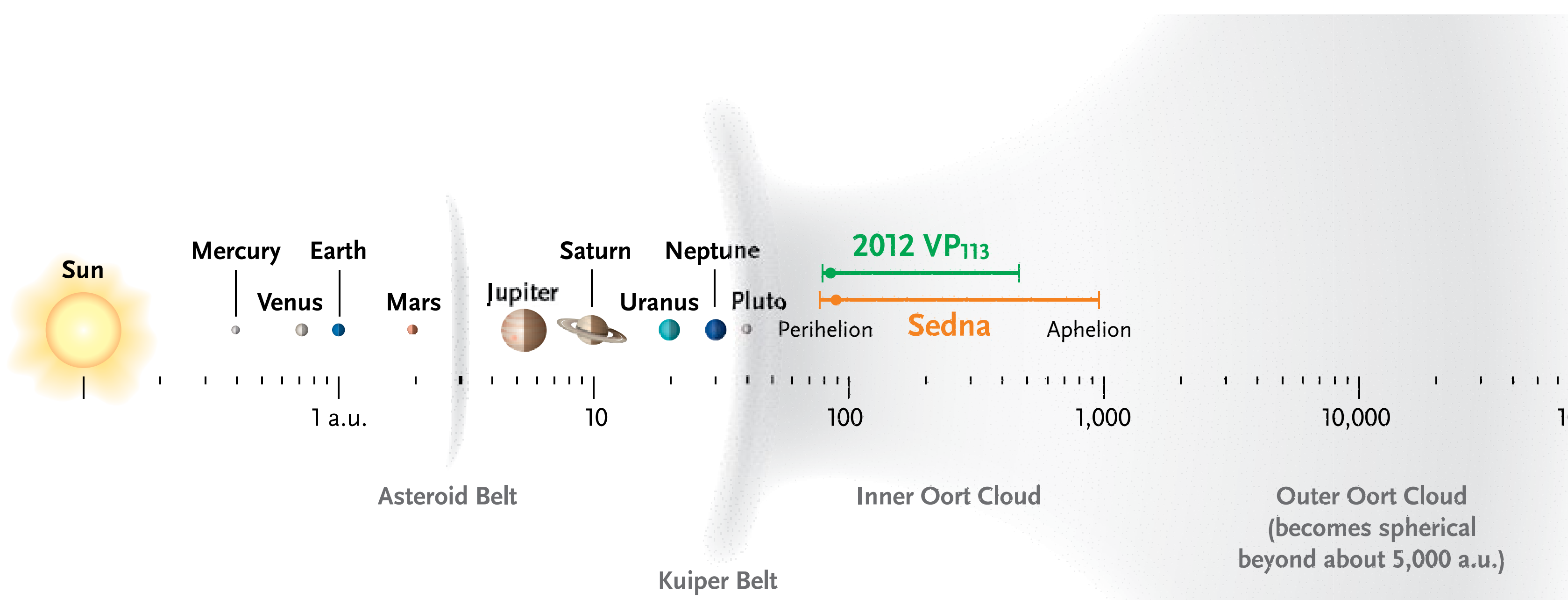
Although the main Kuiper Belt ends around 48 a.u., there is another large reservoir of objects in the distant Solar System from which the long-period comets originate. Long-period comets generally have orbits that reach out tens of thousands of a.u. and tilted every which way compared with the planets' nearly flat orbital plane (the planets essentially all lie in the ecliptic).

The reservoir that supplies these comets is called the Oort Cloud after Jan Oort, the Dutch astronomer who first proposed such a reservoir in 1950. The Oort Cloud extends over one-third of the way to the nearest stellar system, Alpha Centauri, or about 100,000 a.u. It likely contains around a trillion objects larger than 1 km across, with orbital periods of a few million years. It is well beyond the heliosphere, the region that ends where the solar wind gives way to the interstellar medium and through which the Voyager probes are now passing at around 120 a.u.

The Oort Cloud likely arose during our Solar System's planet-building epoch. During the Solar System's formation, many sizable objects formed in the giant planet region. Most of these objects became incorporated into the planets, but gravitational interactions with the growing planets tossed some from the region. The majority of them were ejected from the Solar System into interstellar space, but 1 to 10 percent would not have had enough energy to escape and thus would have ended up in the distant outer Solar System.

An object thrown outwards that does not escape the Sun's gravity will have an elliptical orbit that might take it to thousands or tens of thousands of a.u. But the orbit will still have a closest approach to the Sun (perihelion) that brings it back to the location from which it was originally scattered out. Thus any scattered object will still have part of its orbit within the giant planet region (5-30 a.u.) and at some point will again strongly gravitationally interact with the massive planet that threw it out. This will lead to either an eventual collision or complete ejection from the Solar System.

The Oort Cloud assembled from these eccentric objects at thousands to tens of thousands of a.u., where they are weakly bound to our star. This is where the gravity of the Sun wanes to the point that the gravitational influence of nearby stars, the galactic centre, and the Milky Way's bulk start to be significant. This tidelike effect can move an object's perihelion out far enough past the planets to a point beyond any further strong interactions with Jupiter and its kin. This interaction randomises inclinations and orbits of Oort Cloud objects over



*Objects are not to scale

TOWARDS THE OORT As this diagram shows, Sedna and 2012 VP113 lie in a far-flung region of our Solar System that some astronomers refer to as the inner Oort Cloud (IOC). Experts suspect that the population of objects in the IOC may be larger than that of the Kuiper Belt. S&T: GREGG DINDERMAN (2)

time, and it causes some of them to be lost into interstellar space while others are thrown back into the planetary arena to become long-period comets.

The inner Solar System may actually experience comet showers from random close stellar encounters. These are rare events when a star passes within about 100,000 a.u. of our Sun. Such events, which happen every few tens of millions of years or so, likely only increase the comet flux by a few tens of percent. The next known close encounter will be with the star Gliese 710, which will pass about 70,000 a.u. from our Sun in 1.5 million years. Researchers have suggested these stellar encounters could cause extinction events here on Earth by triggering a storm of comet impacts on the surface, but the interactions are very difficult to predict.

The Inner Oort Cloud

So what about the no man's land between the Oort Cloud at thousands to tens of thousands of a.u. and the Kuiper Belt at a few tens of a.u.? Astronomers had thought no objects would exist with orbits entirely in this middle region, since here the galactic tide is not strong enough to move the perihelion of an object out of the planetary region.

Then Sedna was discovered in 2003, during a shallow survey using the 1.2-metre Samuel Oschin Telescope at Palomar that covered most of the observable sky in the Northern Hemisphere. About 1,000 km in size, Sedna became the first object known to occupy this empty quarter for its entire orbit, with a perihelion (closest distance to the Sun) of 76 a.u. and an outer point of 532 a.u. It was so unusual and unexpected that astronomers had to rethink the formation of our Solar System. Ten years later, Chad Trujillo (Gemini Observatory) and I discovered 2012 VP_{113}, which has a perihelion even farther away than Sedna's at 80 a.u., though surprisingly it has a smaller outer point (265 a.u.). Both objects are on very stable orbits. These objects currently do not gravitationally interact significantly with any known mass in our Solar System, including Neptune. However, their highly elliptical orbits mean that they must have interacted with *something* at some point in time.

Some astronomers have called them inner Oort Cloud (IOC) objects, since they are not susceptible to the galactic tide like the more distant outer Oort Cloud objects at thousands of a.u. IOC objects thus follow orbits that have remained stable from primordial times and are essentially fossilised imprints from their formation mechanism.

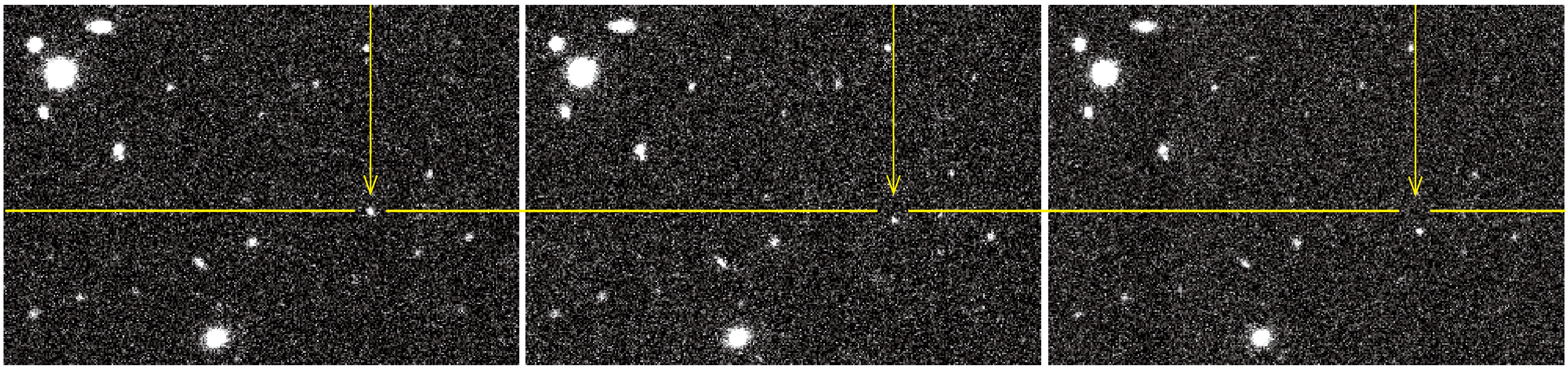
Theorists have proposed several viable IOC formation scenarios, all of which require the Solar System to have been in a state vastly different than it is now. One idea is that a small rogue planet, tossed out of the giant planet region, could have dragged smaller objects with it or perturbed objects out of the Kuiper Belt and into the IOC on its way out. This planet could have been entirely ejected from the Sun's family of bodies or still be lurking in the distant Solar System today.

Another theory is that IOC objects are captured objects that were ejected from other star systems that happened to be near our Sun during its formation in the original birth cluster and were then swept up by our star. A third, related concept is that a close stellar passage to our Sun sometime over the age of the Solar System could have produced objects like we see in the IOC

> **It was so unusual and unexpected that astronomers had to rethink the formation of our Solar System.**

either by tugging objects in our Solar System outwards or losing objects to our Sun (or both), but such a passage would have to have been within a few hundred a.u. This is very unlikely and would probably have disrupted the outer Oort Cloud.

But the leading scenario is that the IOC objects are native to our Sun and came to inhabit the region they do during a time when the gravitational tugs from outside were much stronger on the Solar System than they currently are. This stronger tide would have perturbed objects closer to the Sun and been able to move their perihelia out to our system's outer reaches. A stronger tide would have occurred during our Sun's genesis in its birth cluster, as many other star systems were nearby. Theorists have simulated such a situation, finding that if our Sun originated in at least a moderately dense birth cluster (with a core packing 300 solar masses or more in a single cubic light-year), the gravitational interaction of our system with other stars could have produced IOC objects like Sedna and 2012 VP_{113}. Thus the development of the IOC suggests our Sun grew up with a lot of siblings,



FAINT TRAVELLER On November 5, 2012, the author, together with Chad Trujillo, discovered the inner Oort Cloud object known as 2012 VP_{113}. The discovery images above were taken about two hours apart with the Dark Energy Camera at Cerro Tololo in Chile. SCOTT SHEPPARD / CARNEGIE INST. FOR SCIENCE

GOOD EYE The Blanco 4-metre telescope at the Cerro Tololo Inter-American Observatory in Chile. The author and Chad Trujillo used the telescope's Dark Energy Camera to take the discovery shots shown on page 36. T. ABBOTT AND NOAO / AURA / NSF

which today are dispersed throughout the galaxy.

All the above concepts are testable, with each predicting different orbital distributions for the IOC population. For instance, 2012 VP_{113} is more tightly bound to the Sun than is Sedna, meaning it would need a bigger outside influence to raise its perihelion. If IOC objects are captured objects from outside the Solar System, they should have an assortment of orbital inclinations to the ecliptic, as capture should not strongly depend on the direction the objects came from. Objects scattered out from the inner Solar System should show a flatter inclination distribution, reflecting their origin near the plane of the planets.

The modest inclinations of Sedna (12°) and 2012 VP_{113} (24°) suggest they formed within our Solar System. Sedna's extremely red colour also correlates well with the known classical Kuiper Belt objects. 2012 VP_{113}'s more moderately red colour suggests it formed in the giant planet region. We need a bigger sample to say much more about the IOC objects.

What's Still Out There?

Sedna was discovered using the largest digital camera at the time able to survey the sky efficiently. 2012 VP_{113} was discovered because astronomers are now placing these big digital cameras on larger telescopes. The Dark Energy Camera on the Blanco 4-metre telescope at the Cerro Tololo Inter-American Observatory, which Chad and I used to discover 2012 VP_{113}, covers about 2.7 square degrees per image. This is a factor of several times more sky area than any previous camera on a 4-metre or larger telescope, covering about 11 full Moons in each image. We are continuing our survey for distant objects and expect to find several more IOC objects in the next few years, but we will only cover a fraction of the sky. The Large Synoptic Survey Telescope, which the National Science Foundation is building in Chile, will cover a much larger portion of the sky and to the faint magnitudes needed to discover IOC objects in bulk. But it is still a decade away.

From the discovery of Sedna and 2012 VP_{113} and the small amount of sky searched to date, we believe about 1,000 objects larger than 1,000 km in size exist in the IOC, as well as many more smaller ones. The IOC population is

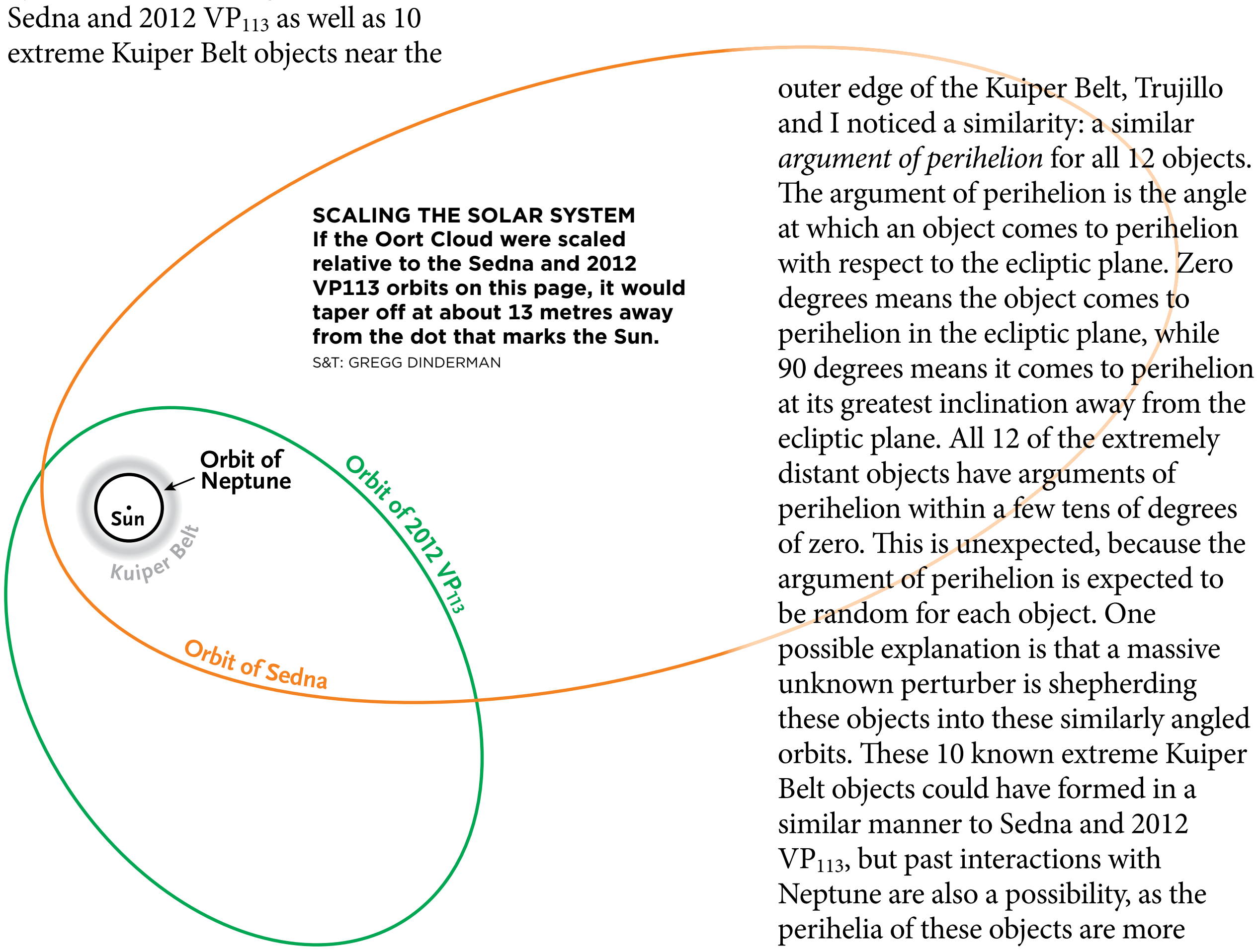
likely larger than the main asteroid belt or Kuiper Belt. Several are probably bigger than Pluto, and some could even be bigger than Mars or even Earth. Objects get very faint at far distances, so big objects could easily lurk in the outer Solar System. We see objects by their scattered sunlight, which has to travel out to the object, reflect off its surface and travel back to Earth. An object twice as far away is 16 times fainter. Because of this, we can only detect Sedna and 2012 VP$_{113}$ for a fraction of their orbits, when they happen to be near their closest points to the Sun. We would not spot them or even Mars-size objects on similar orbits most of the time because they would be too distant and thus too faint.

No more giant planets likely hide in our Solar System, as NASA's Wide-field Infrared Survey Explorer spacecraft would have detected these large planets' warm atmospheres in the infrared. Giant planets give off more heat than they receive from the Sun, because their atmospheres are still dissipating energy they acquired from the planet” formation. Smaller worlds with minimal atmospheres, however, would be cold and frozen with no detectable heat signatures.

Some circumstantial evidence exists that a big object lies in the outer Solar System. When looking at the orbits of Sedna and 2012 VP$_{113}$ as well as 10 extreme Kuiper Belt objects near the outer edge of the Kuiper Belt, Trujillo and I noticed a similarity: a similar *argument of perihelion* for all 12 objects. The argument of perihelion is the angle at which an object comes to perihelion with respect to the ecliptic plane. Zero degrees means the object comes to perihelion in the ecliptic plane, while 90 degrees means it comes to perihelion at its greatest inclination away from the ecliptic plane. All 12 of the extremely distant objects have arguments of perihelion within a few tens of degrees of zero. This is unexpected, because the argument of perihelion is expected to be random for each object. One possible explanation is that a massive unknown perturber is shepherding these objects into these similarly angled orbits. These 10 known extreme Kuiper Belt objects could have formed in a similar manner to Sedna and 2012 VP$_{113}$, but past interactions with Neptune are also a possibility, as the perihelia of these objects are more within Neptune's reach.

The chemical composition of the distant objects is largely unknown, but Sedna appears to have methane ice on its surface. IOC objects are likely frozen ice balls that could be part of what the planets formed from, providing needed volatiles and organics for life here on Earth and possibly elsewhere. Determining their compositions and where and how they got to their present locations will tell us details about our Sun's birth environment and our Solar System's formation. To answer these questions we need to find many more IOCs, in order to look for trends in the population's physical and dynamical characteristics. The hunt is on. ✦

WIDE-FIELD WONDER When operational, the Large Synaptic Survey Telescope facility, here shown in a photo-simulation composite, will provide time-lapse digital imaging of faint astronomical objects such as those found in the inner Oort Cloud. LSST



SCALING THE SOLAR SYSTEM If the Oort Cloud were scaled relative to the Sedna and 2012 VP113 orbits on this page, it would taper off at about 13 metres away from the dot that marks the Sun.
S&T: GREGG DINDERMAN

Scott S. Sheppard is an astronomer in the Department of Terrestrial Magnetism, Carnegie Institution for Science (Washington, D.C.). If Guinness World Records had a record for moon discoveries, Sheppard would hold it.

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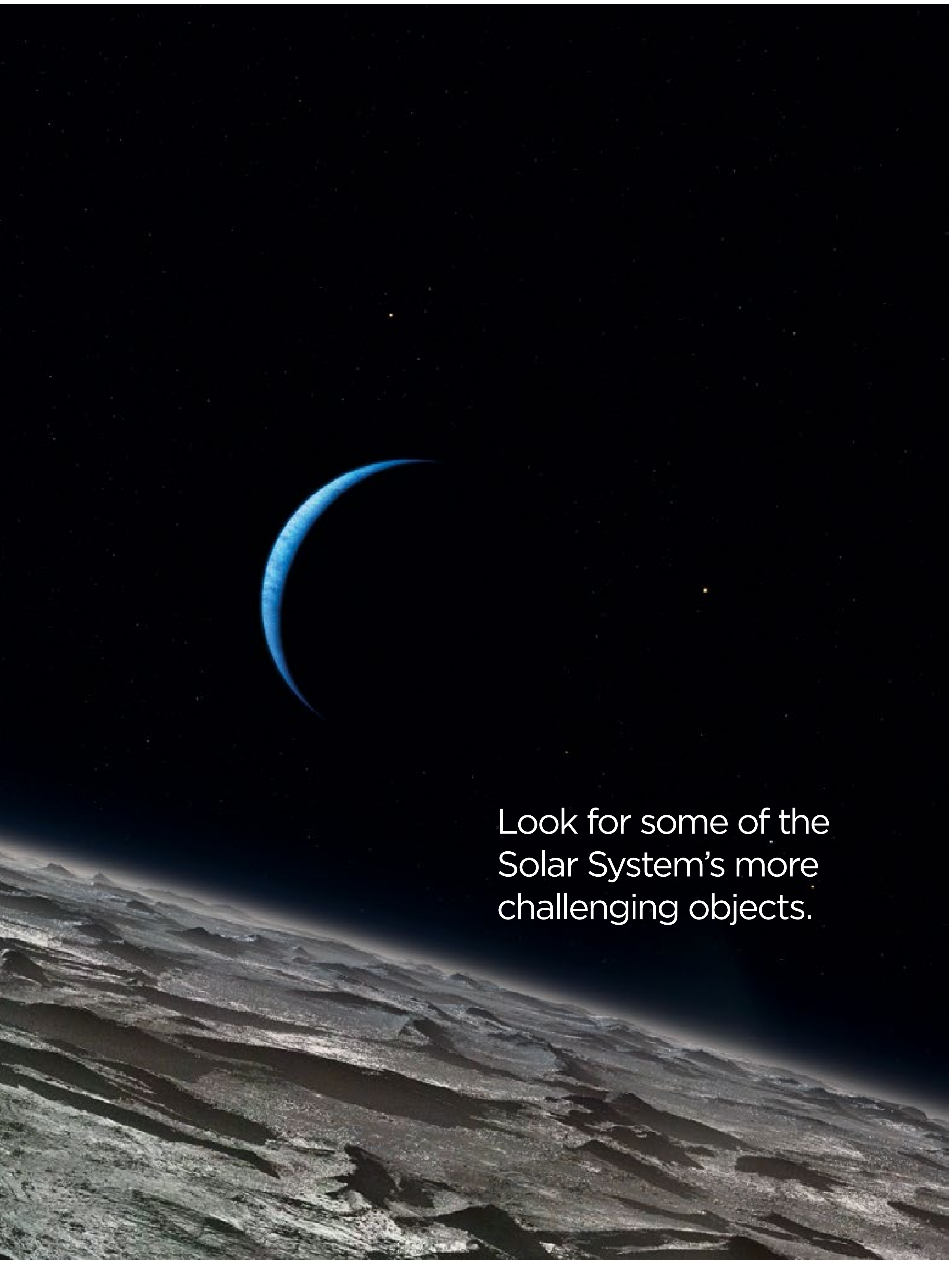
Observing Minor Moons

TERRY N. TREES

My earliest memories out under the stars are of observing Mars during its close approach in 1954. That's 60 years ago, and when I think back to that time, I don't think anyone I knew ever thought of trying to see Phobos or Deimos — or, for that matter, any other of the smaller Solar System moons. Back then, we knew that all the planets except Mercury, Venus and Pluto had moons, but we also knew you were limited to viewing Earth's moon, the four brighter moons of Jupiter, and Saturn's largest moon, Titan. Maybe your telescope was large enough to allow you to identify a few more of Saturn's moons as well, but I don't remember anyone trying for Neptune's Triton or any of the moons of Uranus.

Times have changed. The smaller-sized telescopes of visual observers have been supplanted by large Dobsonians. And while light pollution has limited



Artist's impression of how Triton, Neptune's largest moon, might look from high above its surface. The distant Sun appears at the upper left and the blue crescent of Neptune right of center. ESO / L. CALÇADA

the value of urban/suburban observing sites, many amateurs haul large light buckets to remote dark sky sites and see many objects considered impossible by amateurs in the 1950s.

Thus, the observation of Solar System moons has progressed from the large, bright moons, such as the Galilean moons of Jupiter, to the medium-bright moons, like Titan and Rhea, to dim ones such as the Uranian moons and Triton, and on to challenging moons like Phobos, Deimos, Himalia and Phoebe. As amateur instruments increased in size, visual limits dissolved, and dimmer targets became more possible.

What Have I Seen?

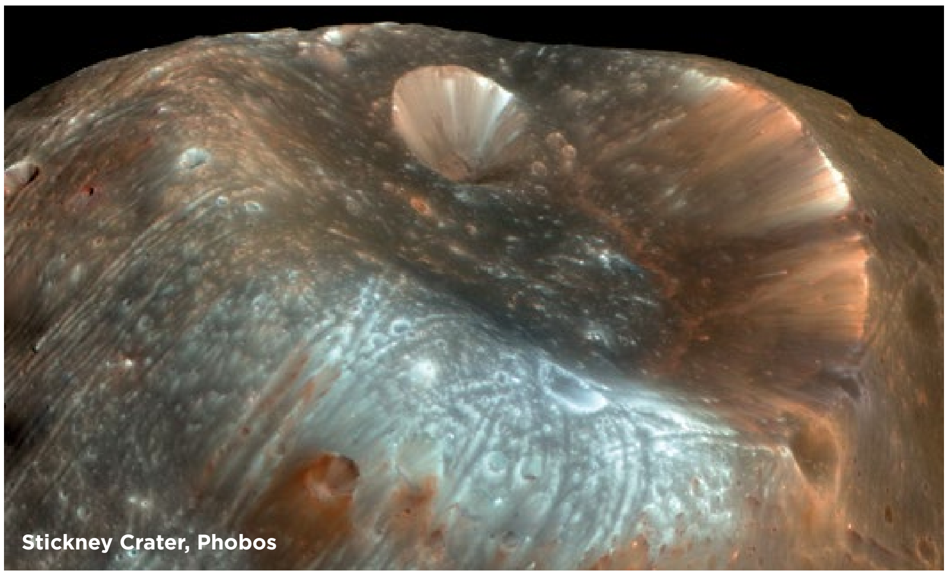
I've observed 22 Solar System moons: 1 of Earth (of course), 2 of Mars, 5 of Jupiter, 8 of Saturn, 5 of Uranus, and 1 of Neptune. These are visual observations, using just a telescope and an eyepiece. No cameras or image intensifiers were involved.

The first truly minor moons I observed were Phobos and Deimos. They were shown to me through a 28-cm astronomy club telescope during the close approach of Mars in 2003. The club member running the telescope at the time employed an occulting bar eyepiece to help defeat Mars' glare. Later I found Deimos with my 20-cm LX-200 while using an occulting filter eyepiece to snag it. (See p. 41 for more on occulting bars and filters.) Both observations were conducted in light-polluted suburban skies. Over the years, I've also observed Uranus' challenging moon Miranda and Jupiter's challenging moon Himalia in the very dark skies of a rural star party.

How Do You Find Them? What Do You See?

As you can imagine, observing minor moons is much like observing asteroids. The fun and challenge is not in the details you see; it's in proving that you successfully observed your target, i.e. proving which of the small objects in the field of view is that target. And how do you do that? At first I drew what I saw and compared that to data from planetarium programs. I now use the asteroid-hunting method described by the Astronomical League **(astroleague.org/al/obsclubs/asteroid/astrclub.html)**. On Day 1, locate an asteroid (or moon) and mark its location on a star chart. On Day 2 (perhaps the next night or the first clear night after Day 1, which could easily be many days later), locate the same object and mark its new location on the star chart. Finally, using the object's original marked position, return your telescope to that spot and verify that it's no longer there.

The following are some examples of what I've seen as described in my logs.



Stickney Crater, Phobos

NASA / JPL / UNIVERSITY OF ARIZONA

20 Challenging Moons Targetable by Larger Amateur Telescopes

Moon	Mean Dia. (km)	Mag (v)	Discovery
Mars			
I – Phobos	22	11.4	A. Hall, 1877
II – Deimos	12	12.5	A. Hall, 1877
Jupiter			
V – Amalthea	167	14.1	E. Barnard, 1892
VI – Himalia	170	14.2	C. Perrine, 1904
VII – Elara	85	16.3	C. Perrine, 1905
Saturn			
I – Mimas	396	12.8	W. Herschel, 1789
II – Enceladus	504	11.8	W. Herschel, 1789
III – Tethys	1066	10.3	J. Cassini, 1684
IV – Dione	1123	10.4	J. Cassini, 1684
V – Rhea	1529	9.7	J. Cassini, 1672
VII – Hyperion	270	14.4	Bond & Bond, Lassell, 1848
VIII – Iapetus	1471	11.0 (var)	J. Cassini, 1671
IX – Phoebe	220	16.5	W. Pickering, 1898
X – Janus	180	14.4	A. Dollfus, 1966
Uranus			
I – Ariel	1158	13.7	W. Lassell, 1851
II – Umbriel	1169	14.5	W. Lassell, 1851
III – Titania	1578	13.5	W. Herschel, 1787
IV – Oberon	1523	13.7	W. Herschel, 1787
V – Miranda	472	15.8	G. Kuiper, 1948
Neptune			
I – Triton	2706	13.5	W. Lassell, 1856

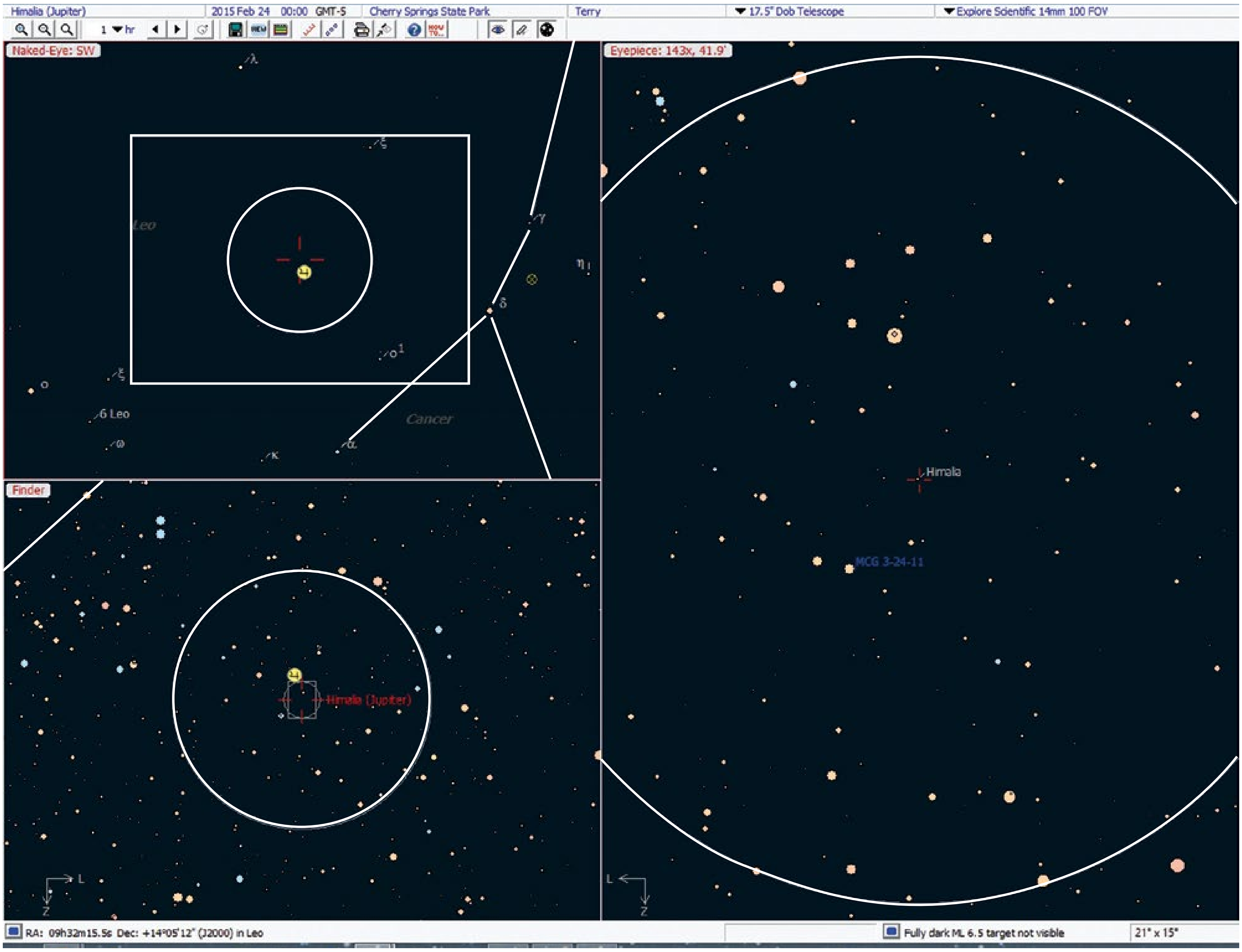
When I observed Deimos with my 20-cm scope, I used a 25-mm Orthoscopic eyepiece with a violet occulting filter and 3× Barlow, resulting in 240×. I drew a map of the field of view (FOV), showing Mars, a few field stars, and a very faint dot about three Martian diameters from the planet. Comparing the angle of lines going from the dot to Mars, and from Mars to the brightest nearby star, I saw the same pattern in my planetarium software. Deimos was seen right where it was predicted to be. There was no sign of Phobos, which my software indicated should have been between Deimos and Mars, about one planetary diameter from Mars. I imagine it was buried in light pollution and/or Mars' glare.

I found Uranus' moon Miranda by a somewhat similar technique. While using my 44-cm Dobsonian telescope at the aforementioned star party, a 9-mm Nagler eyepiece resulted in 223×. I observed Uranus and made a sketch of the FOV. The very few visible field stars

"Deimos was seen right where it was predicted to be. There was no sign of Phobos, which my software indicated should have been between Deimos and Mars."

were later confirmed by my planetarium software. Miranda's predicted magnitude that night was +16.5. That's dim, but the skies were very dark. Nevertheless, I was surprised to later find a dot in my drawing right where Miranda was predicted to be. There were no field stars displayed near Miranda in my drawing or by the software.

Jupiter's VI moon, Himalia, was my next target after I failed on several attempts to find the planet's V moon, Amalthea. Amalthea is somewhat brighter than Himalia, but is very near the planet, masked in glare. My Himalia observations were also made at the star party, this time in 2010. We've had good luck with the weather at this star party over the years, maybe losing only four nights of the 25 or 30 we've been there. I used a 20-mm eyepiece for 100× and a



Reliable planetarium software increases the accuracy of minor moon searches. The author used *SkyTools 3 Pro* to plot a naked-eye diagram, finder diagram and eyepiece field-of-view chart for the target moon, Himalia (Jupiter VI).

12-mm eyepiece for 167× with my 44-cm Dobsonian. The beginning of the week suffered from wind gusts. Sunday night, I had several weak 'maybes' for Himalia. Monday was similar. Tuesday, I was sure I'd observed Himalia, and it was a dim dot, slowly blinking on and off. I assumed the wind gusts were causing much of that. On Wednesday, I confirmed Tuesday's Himalia observations by returning to my previous position and verifying nothing was visible there. I then went to Himalia's next predicted position and easily located it. I showed it to two of my friends. Thursday, one of my friends used my charts to find Himalia with his 31-cm f/6 Dobsonian.

When printing charts for Himalia, I inserted a circle that represented the FOV for my 20-mm eyepiece and my f/4.5 44-cm Dobsonian. Himalia was about 3/4 of the FOV away from Jupiter. As soon as Jupiter was off the eyepiece, dim stars appeared, allowing me to star-hop to Himalia's location. This became easier as the days passed and I became more familiar with the patterns of these dim stars. Because we saw Himalia move from one day to the next, there is no question in our minds we observed Jupiter VI. But even though Himalia was fairly distant from Jupiter at the time, the glare was still significant.

Techniques

There are many planetarium programs that give excellent asteroid position predictions. Add a FOV circle representing your eyepiece and scope to aid in the asteroid's identification and have at it. I learned the hard way that many software packages' minor moon predictions are not accurate at all, so I use the NASA/JPL HORIZONS Web-Interface **(http://ssd.jpl.nasa.gov/horizons.cgi)** to produce an ephemeris. If you're not familiar with the term 'ephemeris,' it's a table that lists an astronomical object's predicted positions. (See skypub.com/ephemeris for more tips on generating ephemerides.)

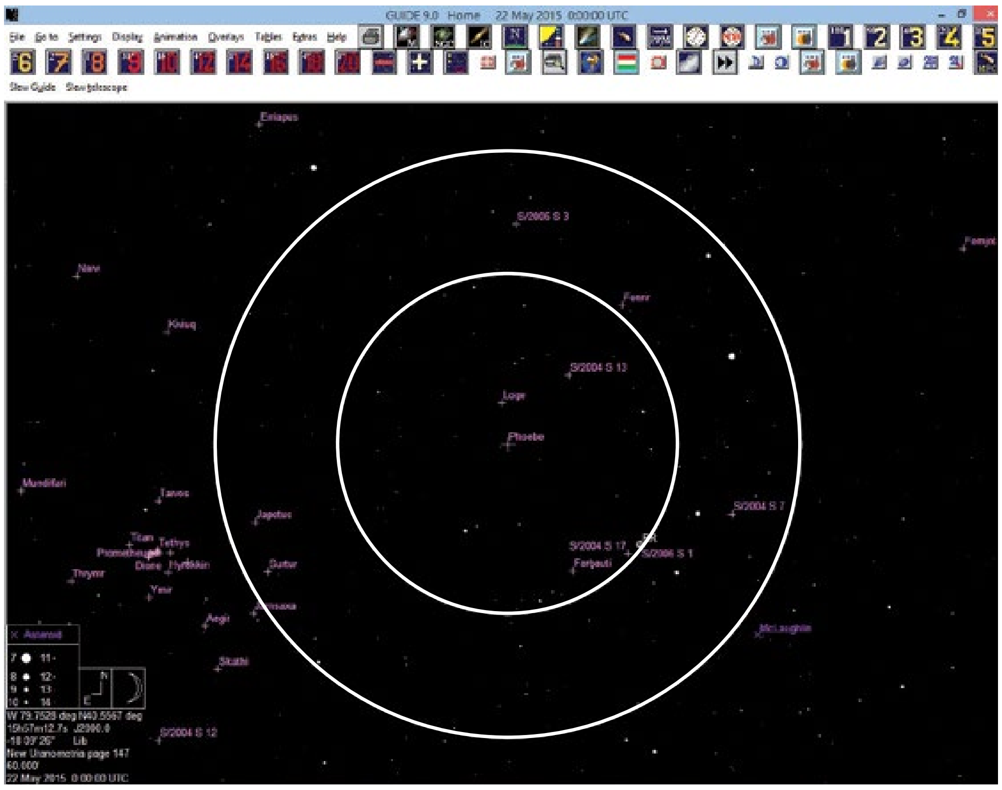
Generate an ephemeris for your target and compare its output with what's predicted by your planetarium software. If you find it checks out, generate ephemerides for several moons on several different widely separated dates and again compare

NASA's Galileo spacecraft provided our best look at the inner Jovian moons Thebe, Amalthea, Adrastea and Metis (left to right) in January 2000. The moons are shown in their correct relative sizes; the large impact crater on Amalthea is about 89 kilometres across. NASA / JPL / CORNELL UNIVERSITY

them with your software's predictions. You might be able to prove complete reliability for your program and not need to generate any future ephemerides.

I've successfully tested both *SkyTools 3 Pro* (**skyhound.com**) and *Guide 9.0* (**www.projectpluto.com**). They're very straightforward, and I use them without concern for predictive accuracy. The Himalia chart included here was produced with *SkyTools*. It shows a naked-eye diagram, a finder diagram and, most importantly, an eyepiece FOV diagram for the target moon, Himalia. A minor shortcoming of *SkyTools* is that it doesn't yet provide predictions for Jupiter's moon Elara or Saturn's moon Janus, but Version 4 will correct that. (The absence of Janus may not be an issue since it has never been visually observed to the best of my knowledge.) By the way, either moon can be manually plotted from ephemeris data for a given point in time by using what *SkyTools* calls 'Sky Marks.' *Guide* has a reputation for plotting Solar System moons with extreme accuracy. It certainly does for me. While its graphics might not be as modern as those of some of its competitors, they are customisable and perform excellently. The authors of both software packages are easy to contact and provide excellent support.

Let's walk through a set-up for minor moon observations, assuming we want to observe Phoebe (Saturn IX). Saturn will be at opposition and high in the sky at midnight on May 22, 2015. Open Guide, set the date, time, and observing location as accurately as possible. Use the 'Go to > Planets' option to retrieve positional data for Phoebe. Zoom in and out to get the desired level of chart detail and, finally, increase/decrease the number of shown stars to bring the dimmer ones to a magnitude comparable to Phoebe's. The results should resemble the *Guide* chart pictured here. (NB: Since I had previously successfully tested Guide against the NASA/JPL HORIZONS data, I saw no need to generate and compare an ephemeris to Guide for this observation attempt.)



When simulating your telescope's field of view with your planetarium software, include stars with magnitudes comparable to that of your target object, as the author has done in this *Guide 9.0* finder chart for Phoebe (Saturn IX). PROJECT PLUTO

The inner circle represents the FOV of a 9-mm 100° eyepiece with my 44-cm Dobsonian. Notice that Saturn is buried in the plots of its major moons in the lower left of the chart and out of the FOV. Thus, glare should be reduced as you search for Phoebe's dim dot. Theoretically, Phoebe should be easy to identify based on the pattern of stars through the eyepiece, but if it's not visible, the next step would be to go to a similar focal length Orthoscopic or Plössl eyepiece and try again. With much less glass, these eyepieces should absorb less light; that might help Phoebe's visibility. An eyepiece of higher magnification may also be of assistance, since it increases contrast. A benefit of both is that Saturn might be out of the FOV.

What Future Targets Remain?

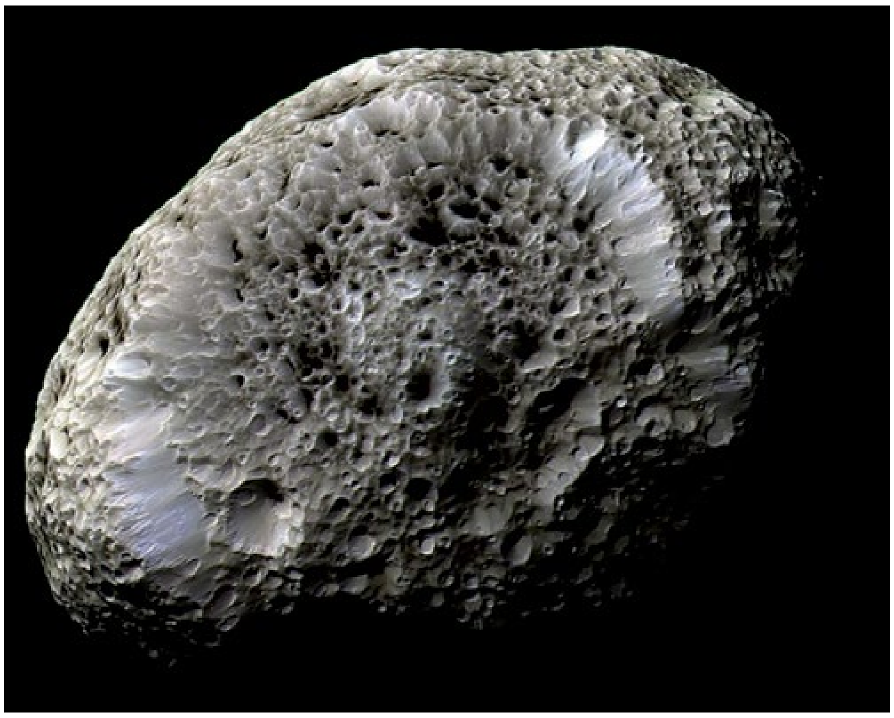
When I first began this project, I thought it would be a nice challenge to observe all the Solar System's moons

that were known when I was a child: Earth 1, Mars 2, Jupiter 12, Saturn 9, Uranus 5, and Neptune 2. I then noted the magnitudes of some of Jupiter's and Neptune's minor moons and very quickly ruled them out.

Jupiter and Saturn do, however, provide some moons I have yet to see that are *possibly* within the magnitude range of our current scopes. Jupiter has Amalthea (magnitude 14.1) and Elara (magnitude 16.3). Saturn has Janus (magnitude 14.4) and Phoebe (magnitude 16.5). Perhaps some are possible from a very dark site, but Amalthea never ventures much more than one Jovian diameter from Jupiter so perpetually resides in intense glare. Someone once related to me that no one has ever visually observed Amalthea except for E. E. Barnard when he first discovered it. In fact, there have been other sightings: it's been observed through the 47-cm Clark refractor at the Dearborn Observatory (Northwestern University); the 23-inch Clark at the Halsted Observatory (Princeton University); the 58-cm Clark at McCormick Observatory (University of Virginia); and the 66-cm Clark at the United States Naval Observatory. At least a few astronomers have tracked it down, thanks to Alvan Clark & Sons!

Another possibility is Janus, but it orbits in Saturn's ring system; even when the rings are edge-on, Saturn provides more than enough glare necessary to block its observation. So, Elara and Phoebe are probably the only targets that realistically remain. Both follow orbits fairly distant from their planets, but they're also very dim. I might need a larger telescope, but that certainly won't prevent me from trying. ✦

Terry N. Trees **has been an amateur astronomer since he was a child, and has taught astronomy and other science courses at. He and his wife travel extensively to star parties. Trees can be reached at TreesT@Comcast.net.**



When to Seek Minor Moons in 2015-16

Planet	Opposition Dates	New Moons from Earth	Distance
Mars	May 21, 2016	May 6 & Jun 4, 2016	0.5 a.u.
Jupiter	Feb 6, 2015	Jan 19 & Feb 18, 2015	4.3 a.u.
Mar	7, 2016	Feb 7 & Mar 8, 2016	4.4 a.u.
Saturn	May 22, 2015	May 17 & Jun 15, 2015	9.0 a.u.
	June 2, 2016	May 6 & June 4, 2016	9.0 a.u.
Uranus	Oct 11, 2015	Sep 12 & Oct 12, 2015	19 a.u.
	Oct 14, 2016	Sep 30 & Oct 30, 2016	19 a.u.
Neptune	Aug 31, 2015	Aug 13 & Sep 12, 2015	29 a.u.
	Sept 2, 2016	Aug 31 & Sep 30, 2016	28.9 a.u.

Creating an Occulting Filter Eyepiece

Some moons orbit near their planets, so planetary glare is of great concern when trying to locate them. Phobos and Deimos are classic examples of this, but I had glare issues the first time I tracked down Himalia, even though it was distant from Jupiter at the time. Occulting bar or filter eyepieces may be of assistance with these problems.

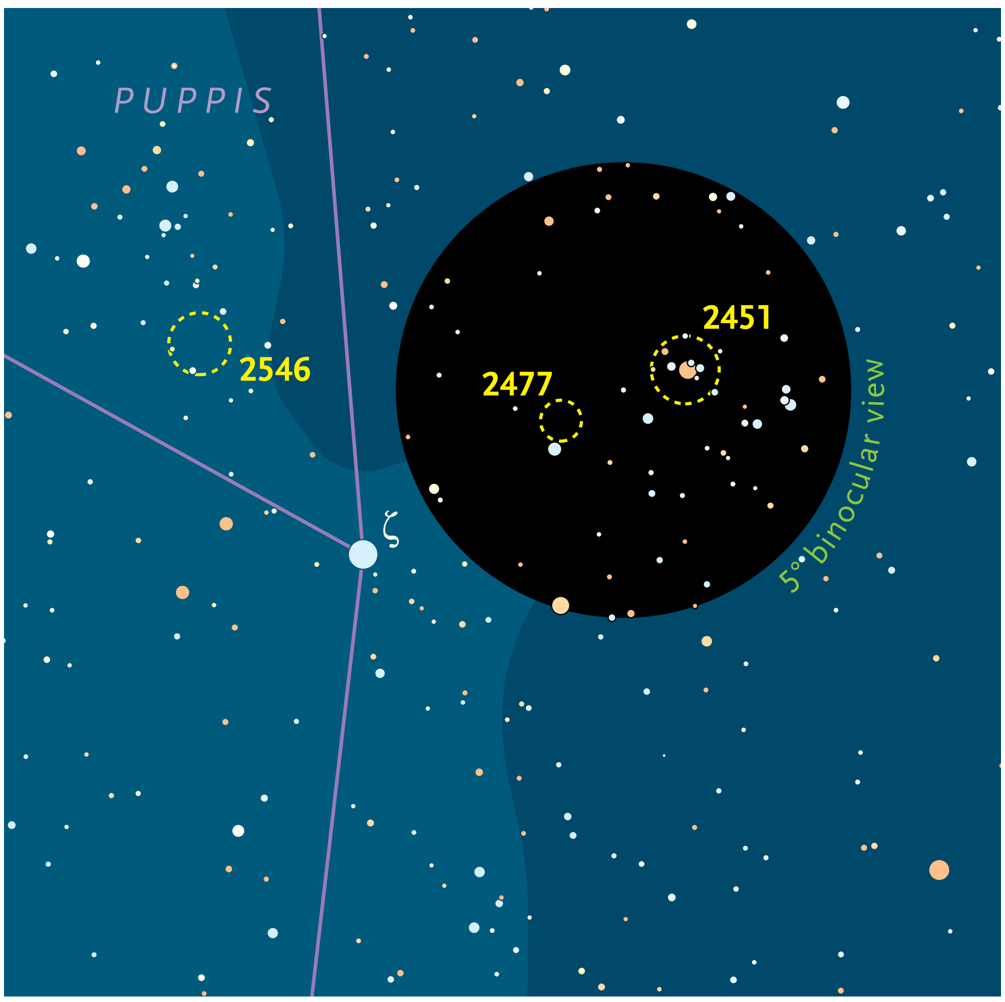
While an occulting bar will entirely block out a planet, an occulting filter will provide a dim image of it. If you have an accurate predictive chart, this may help you locate a dim moon; you'll know where to look in relation to its planet. The bar or filter must be mounted at the eyepiece's focal plane, or a crisp edge won't be generated in the image.

I've made two occulting filter eyepieces. I removed a violet filter from its cell, scored it with a glass cutter and straight edge, broke it in half, and rubbed the "diameter edges" against emery cloth to eliminate small burrs. I then epoxied the two semicircular filter segments to the inside of the field stops of two old, low-power Orthoscopic eyepieces. I attached the pieces to the inside of the field stops in case the glue failed; this position lowered the chances of a loose filter falling onto a mirror surface. Be sure to use something like an Orthoscopic, Kellner or Plössl. Most modern wide-field eyepieces are unsuitable for this project as their focal planes are between internal glass elements.

The author made this occulting filter eyepiece by gluing the halves of a violet filter to the inside stops of a low-power eyepiece. TERRY N. TREES

Gary Seronik
Binocular Highlight

A Trio of Puppis Clusters



The swath of Milky Way running south through Canis Major and into Puppis is rich with open star clusters — some of them well known, some not. Situated near 2.2-magnitude Zeta (ζ) Puppis is a trio of fine binocular targets.

Let's begin west of Zeta with the splashiest cluster of the three, NGC 2451. It's a loose collection of more than a dozen stars scattered across about one degree of sky. Several curving rows of stars seem to emanate from a single, 3.6-magnitude star near the cluster's centre. Through my 10×50 binoculars, it almost looks like a child's connect-the-dots rendering of a face-on spiral galaxy.

Just to the east, and in the same binocular field as NGC 2451, lies NGC 2477. The two clusters are a study in contrasts. Whereas NGC 2451 is a ragged assemblage dotted with several bright stars, NGC 2477 is a rich, compact round glow. But with careful viewing through my 10×50s, I can see that it's neither perfectly round nor uniformly lit — a few individual stars occasionally wink in and out of view. NGC 2477 is a prominent object under dark skies, though it likely won't survive light-polluted conditions as well as its showy neighbour.

For the last (and arguably least) of the clusters, jump east of Zeta to locate NGC 2546. Throuh my 10×50s, this cluster looks like a detached clump of Milky Way. It's somewhat elongated along its north-south axis, and I can make out a dozen or so individual cluster stars. NGC 2546 isn't a particularly stunning find, but since you're in the neighbourhood anyway, why not have a look? ✦

USING THE STAR CHART

WHEN

Early March	10pm
Late March	9pm
Early April	8pm
Late April	7pm

These are standard times — add Daylight Savings if it applies to your location.

HOW

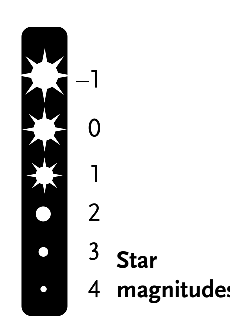
Go outside within an hour or so of a time listed above. Hold the map above your head with the bottom of the page facing south. The chart now matches the stars in your sky, with the circular perimeter representing the horizon and the centre of the chart being the point directly over your head (known as the zenith).

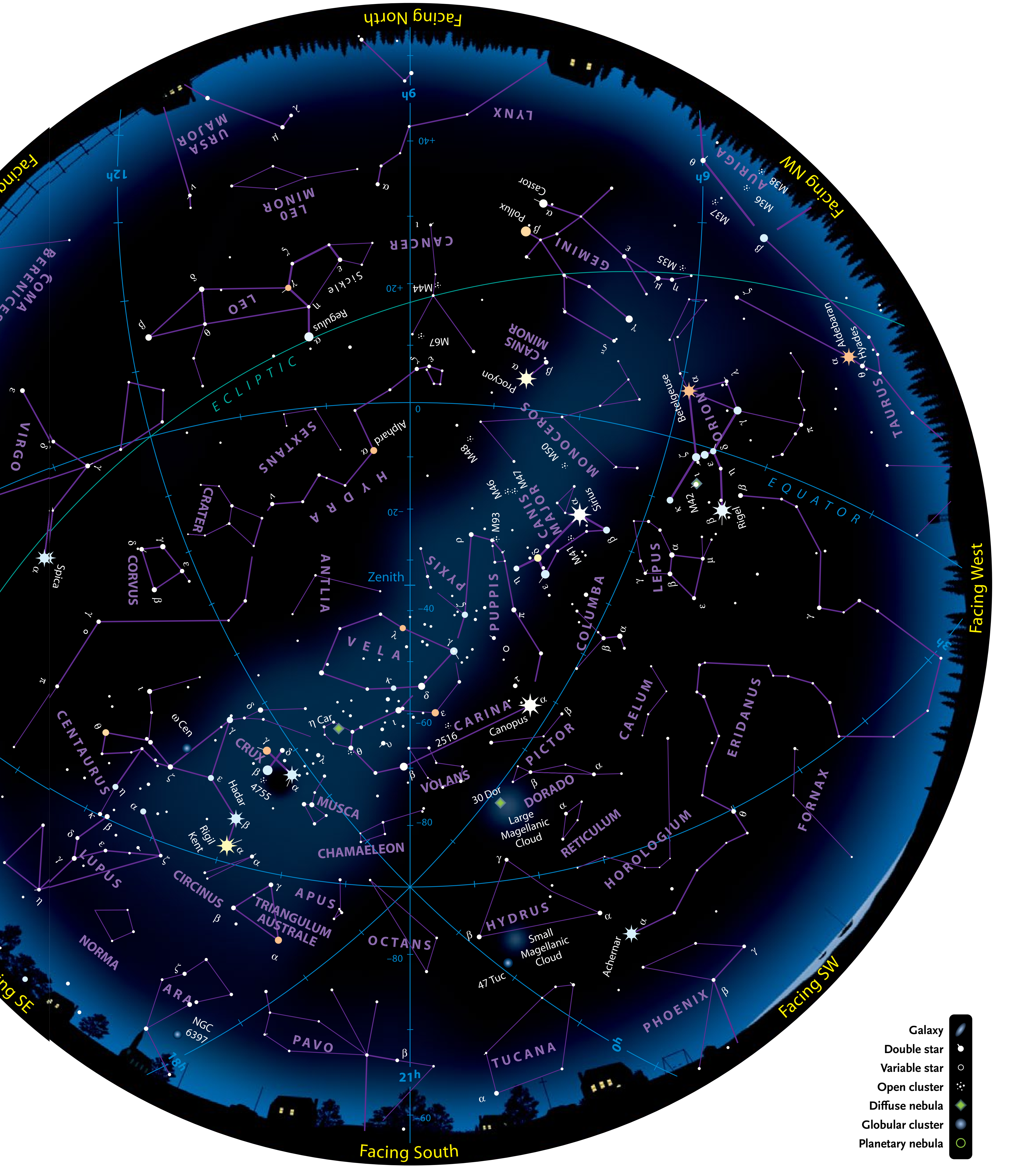
FOR EXAMPLE: Look at the chart, and you'll see that the bright star Achernar at the end of the constellation Eridanus (The River) is about one-third of the way from the southwestern horizon and the middle of the chart. So if you look to the southwest, you'll find Achernar about one-third of the way up from the horizon.

NOTE: The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're much further north of there, stars in the northern part of the sky will be higher and stars in the south lower. If you're further south, the reverse is true.

ONLINE

You can get a sky chart customised for your location at any time at SkyandTelescope.com/skychart




Facing North
Facing NW
Facing West
Facing SW
Facing South
Facing SE
ECLIPTIC
EQUATOR
Zenith
LYNX
URSA MAJOR
LEO MINOR
CANCER
GEMINI
AURIGA
TAURUS
ORION
CANIS MINOR
MONOCEROS
CANIS MAJOR
LEPUS
COLUMBA
PUPPIS
PYXIS
ANTLIA
HYDRA
SEXTANS
LEO
Sickle
Regulus
Alphard
CRATER
CORVUS
VIRGO
Spica
COMA BERENICES
CENTAURUS
VELA
CARINA
Canopus
PICTOR
CAELUM
ERIDANUS
FORNAX
HOROLOGIUM
RETICULUM
DORADO
Large Magellanic Cloud
30 Dor
VOLANS
MUSCA
CHAMAELEON
CRUX
Hadar
Rigil Kent
LUPUS
CIRCINUS
TRIANGULUM AUSTRALE
APUS
OCTANS
HYDRUS
Small Magellanic Cloud
47 Tuc
Achernar
PHOENIX
TUCANA
PAVO
ARA
NGC 6397
NORMA
Castor
Pollux
Procyon
Sirius
Betelgeuse
Rigel
Aldebaran
Hyades
M42
M35
M36
M37
M38
M44
M67
M48
M50
M46
M47
M93
M41
η Car
2516
4755
ω Cen
Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

Fred Schaaf
Tonight's Sky

The Dog Nights of the Nile

Sirius is a mighty sight in many seasons.

SUNSET on the nile In ancient Egypt; the heliacal rising of Sirius marked the beginning of the flood season on the Nile. SURAJ BAADKAR

Before dawn on August 18, 2014, I stood near my favorite local pond looking at Venus and Jupiter and their reflections. That morning, I beheld the two planets forming a brilliant pair only about 1/3° apart — not too much farther apart or much differently situated in the sky than they were when the Magi of Christian tradition might have seen them in August of 3 BC.

Three days earlier, on August 15th, I had seen something just as interesting: the brightest of all stars at its famed 'heliacal rising.' Of course, I'm talking about Sirius, which at this time of year is still and at a convenient for altitude for viewing in the evening hours.

Orion the Hunter, the brightest of all constellations, leads his two hounds across the sky in procession. In Canis Major, the Big Dog, we find Sirius, a star so bright that you'd need to combine the light of Arcturus, Vega and Capella to match its brilliance.

Among the star patterns at this time of the year, Canis Major is second only to Orion in overall brightness. At magnitude 1.5, Epsilon (ε) Canis Majoris, more commonly known as Adhara, is the brightest of all 2nd-magnitude stars. In addition, Adhara is part of a triangle of stars at the south end of Canis Major that rivals Orion's Belt in total brightness. Yet these other fine luminaries of Canis Major are often overlooked because they can't compete with the –1.44 radiance of Sirius itself.

Sirius is often paired with Procyon, the brightest star in the smaller constellation, Canis Minor, the Little Dog. But even though this lesser Dog Star is the 8th brightest star in the heavens, shining at magnitude 0.4, it's often overlooked because of Sirius.

Sirius pulls our gaze away from more than just the other stars of the Big Dog. Sometimes we're so enthralled by its glow that we forget to scan just 4° south of the mighty star to observe one of winter's loveliest open clusters. M41 shines at magnitude 4.5, so if you have suitably dark skies, you can spot it with the unaided eye.

The term 'Dog Days,' used since at least the period of Ancient Greece, refers to the hottest and sultriest part of the Northern Hemisphere summer. The name may have been derived from the older belief that Sirius, the Dog Star, added its heat to the day when it shared the sky with the Sun.

After the Dog Days of summer comes the first sight of Sirius rising just before sunrise — its 'heliacal rising.' For the Egyptian Middle and New Kingdoms (and possibly even earlier periods), the heliacal rising of Sirius was the welcome harbinger of the life-giving annual flood of the river Nile. In fact, the heliacal rising of Sirius was so important that it marked the New Year in the Egyptian calendar.

In modern times, how many of us who enjoy the Dog Nights of late summer in the Southern Hemisphere, observing Sirius in the evenings, also try to look for the heliacal rising of Sirius at August dawns? I've often been up so many hours watching for Perseid meteors that I had to go to bed before Sirius could rise in the later stages of morning twilight.

"After the Dog Days of summer comes the first sight of Sirius rising just before sunrise"

On August 15th last year, I saw Venus and Jupiter, Procyon, and then the last 'herald' of Sirius, Beta (β) Canis Majoris — also known as Mirzam (or Murzim). At magnitude 1.98, Mirzam was easy through binoculars but at the edge of possibility for naked-eye vision; it was just a few degrees above the horizon about 50 minutes before sunrise. But then, about 10 minutes later, there glittered above a distant tree a bright, sparkling light — my dear friend of those nights, Sirius.✦

Fred Schaaf **welcomes your comments at fschaaf@aol.com.**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Astronomy Image by Olly Penrice

Saturn and Jupiter rule the sky

Our Solar System's two largest planets are well placed for viewing.

Autumn is now here and the nights are slowly getting longer. Daylight saving vanish in early April too, so it's time to make the most of our evening stargazing opportunities before the cold, wet winter sets in.

Mercury is on the other side of the Sun from us in early April, but will reappear to the west in the evening sky in the latter half of the month.

Venus is shining brightly in the evening sky, surrounded by other interesting night sky sights – the Pleiades and Hyades star clusters, and the stars of some of most outstanding constellations – Orion, Taurus and Gemini. Look for the Moon nearby on April 21 and 22.

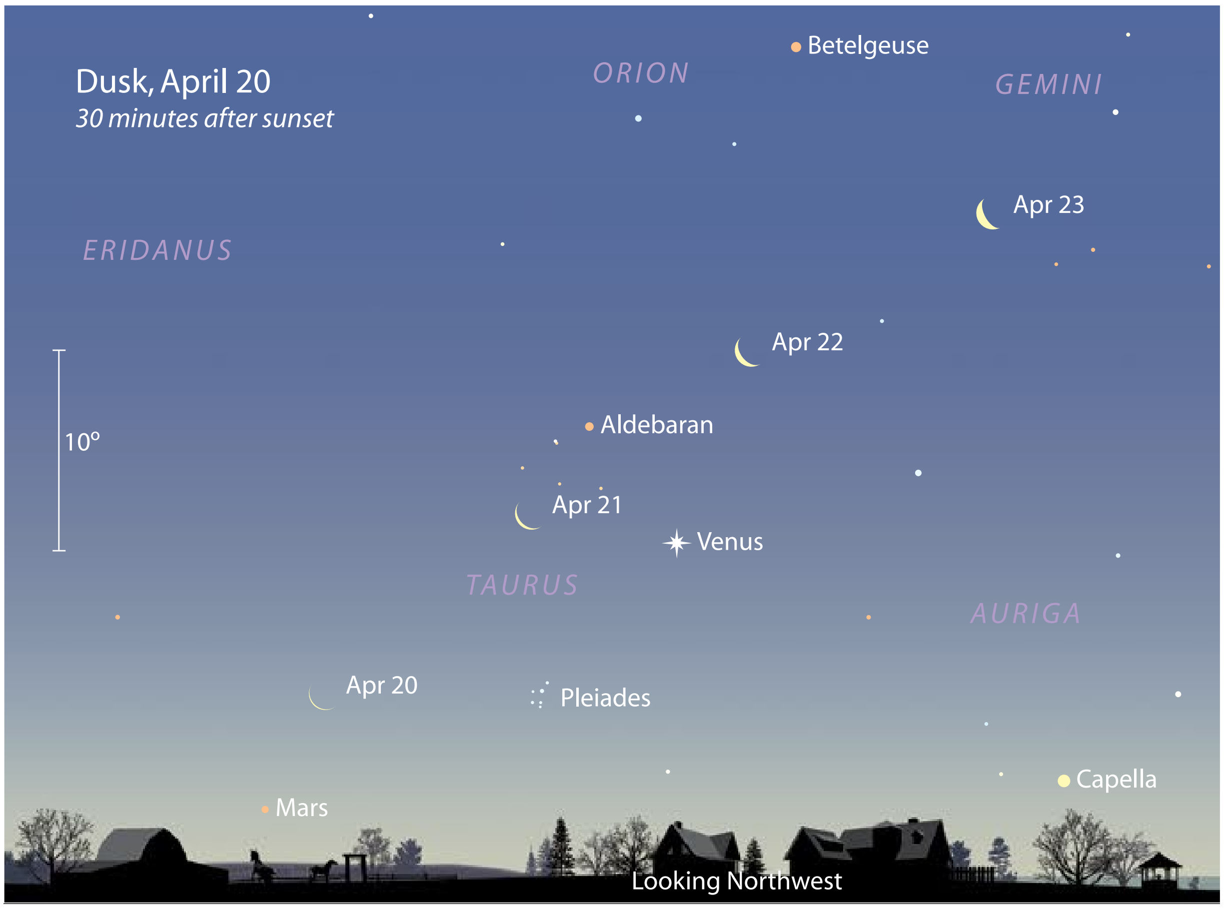
Mars is now very low down in the western sky after sunset, but do take a look for it if your horizon permits. (In other words, as long as you don't have hills, trees or buildings blocking the view.) A thin crescent Moon will be nearby on April 20. The Red Planet will soon disappear into the Sun's glare as it heads around to the other side of our star; it will reappear in the eastern morning sky in August.

Jupiter is still riding high in the northern sky. Although it is now two months past opposition, don't let that put you off – with an apparent diameter of 40 arcseconds and a brightness of magnitude –2.2, it's still the king of planets for stargazers. Have a look for some of its moons, its cloud bands and the Great Red Spot (details on the opposite page).

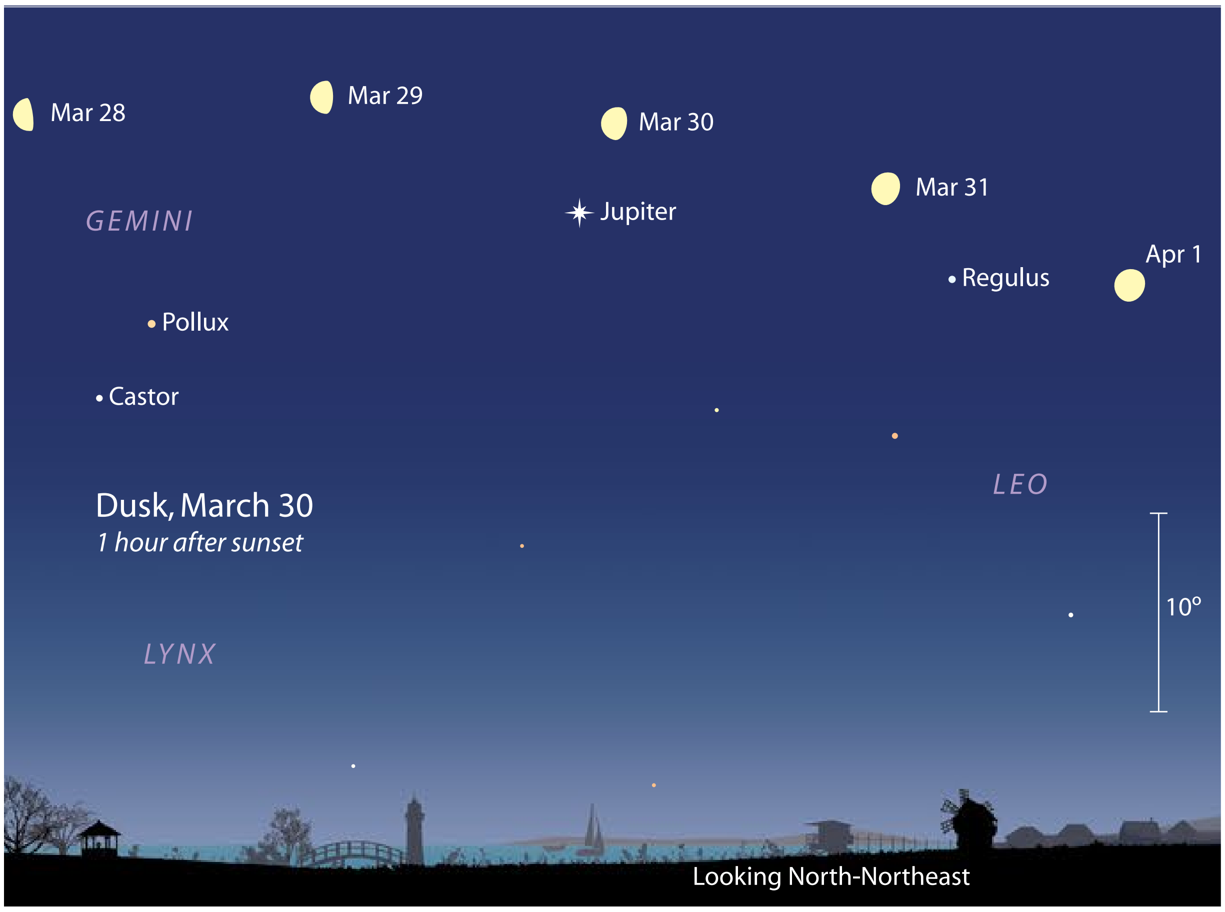
Saturn is heading towards opposition in May. During April, it rises in the east about 9 p.m. at the beginning of the month, becoming 7 p.m. by the end of the month. Take a look on the 8th – the Moon will be very close by.

For both **Jupiter** and **Saturn**, why not try your hand at tracking down some of their smaller moons with your telescope? See the article on pages 36-41 for how to do it.

Finally, the planet **Uranus** is, ordinarily, bright enough to be seen by the unaided eye if you know exactly where to look. But not at the moment, though, as it is on the opposite side of the Sun to us, and therefore lost to our view.



Mars is low on the horizon on April 20, with the thin crescent Moon just above. Venus shines brightly higher in the twilight.



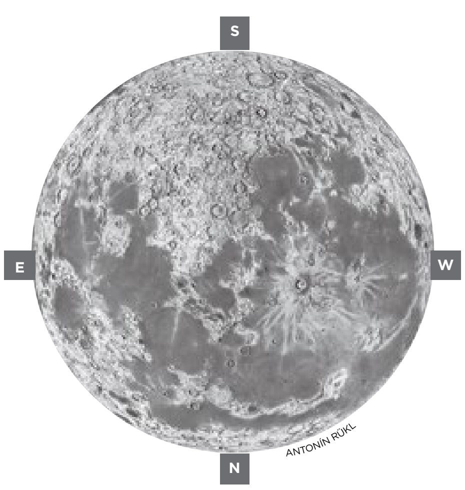
Jupiter is now a couple of months past opposition, but still riding high in the sky in the evening.

Venus (left), Mercury (upper right) and a star shine together on January 15, 2015. JAMIE COOPER

Events Of Note

April	1	Regulus 4° north of the Moon
	4	Full Moon
	5	Spica 3° south of the Moon
	8	Saturn 2° south of the Moon
	9	Antares 9° south of the Moon
	11	Venus 2.5° south of the Pleiades
	12	Last quarter Moon
	18	New Moon
	20	Mars 5° south of the Moon
	21	Venus 8° north of Aldebaran
	22	Aldebaran 0.9° south of the Moon
	22	Venus 7° north of the Moon
	25	First quarter Moon
	30	Mercury at greatest latitude north

Times are listed in Eastern Australia Standard Time



Moon, April 2015

Phases

Full Moon April 4, 12:06 UT
Last Quarter April 12, 03:44 UT
New Moon April 18, 18:57 UT
First Quarter April 25, 23:55 UT

Distances

Apogee April 1, 13h UT
405,923 km
Perigee April 17, 04h UT
360,899 km
Apogee April 29, 04h UT
404,995 km

Jupiter's Red Spot Transit, April 2015

Jupiter is already nice and high as soon as night falls in April, but it shrinks from 42' to 38' wide this month.

Any telescope shows Jupiter's four big Galilean moons. Binoculars usually show at least two or three, occasionally all four.

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold.

MARCH 1, 9:50, 19:46; **2**, 5:41, 15:37; **3**, 1:32, 11:28, 21:24; **4**, 7:19, 17:15; **5**, 3:11, 13:06, 23:02; **6**, 8:58, 18:53; **7**, 4:49, 14:44; **8**, 0:40, 10:36, 20:31; **9**, 6:27, 16:23; **10**, 2:18, 12:14, 22:10; **11**, 8:05, 18:01; **12**, 3:57, 13:52, 23:48; **13**, 9:44, 19:39; **14**, 5:35, 15:31; **15**, 1:26, 11:22, 21:18; **16**, 7:13, 17:09; **17**, 3:04, 13:00, 22:56; **18**, 8:51, 18:47; **19**, 4:43, 14:39; **20**, 0:34, 10:30, 20:26; **21**, 6:21, 16:17; **22**, 2:13, 12:08, 22:04; **23**, 8:00, 17:55; **24**, 3:51, 13:47, 23:42; **25**, 9:38, 19:34; **26**, 5:29, 15:25; **27**, 1:21, 11:17, 21:12; **28**, 7:08, 17:04; **29**, 2:59, 12:55, 22:51; **30**, 8:46, 18:42; **31**, 4:38, 14:34.

APRIL 1, 0:28, 10:23, 20:19; **2**, 6:15, 16:10; **3**, 2:06, 12:02, 21:58; **4**, 7:53, 17:49; **5**, 3:45, 13:40, 23:36; **6**, 9:32, 19:28; **7**, 5:23, 15:19; **8**, 1:15, 11:11, 21:06; **9**, 7:02, 16:58; **10**, 2:53, 12:49, 22:45; **11**, 8:41, 18:36; **12**, 4:32, 14:28; **13**, 0:24, 10:19, 20:15; **14**, 6:11, 16:07; **15**, 2:02, 11:58, 21:54; **16**, 7:50, 17:45; **17**, 3:41, 13:37, 23:33; **18**, 9:28, 19:24; **19**, 5:20, 15:16; **20**, 1:11, 11:07, 21:03; **21**, 6:59, 16:54; **22**, 2:50, 12:46, 22:42; **23**, 8:37, 18:33; **24**, 4:29, 14:25; **25**, 0:20, 10:16, 20:12; **26**, 6:08, 16:03; **27**, 1:59, 11:55, 21:51; **28**, 7:47, 17:42; **29**, 3:38, 13:34, 23:30; **30**, 9:25, 19:21.

These times assume that the spot will be centered at System II longitude 221º. Any feature on Jupiter appears closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly boosts the contrast of Jupiter's reddish, orange and tan markings.

An early-morning comet

David Seargent

At the time of writing, the only good prospect for comet observers with small telescopes in April is the returning comet 88P/Howell. This comet was discovered way back on August 29, 1981, by E. S. Howell, then an undergraduate student working with C. T. Kowal in the search for supernovae using the 46-cm Schmidt telescope at Palomar Observatory in the USA.

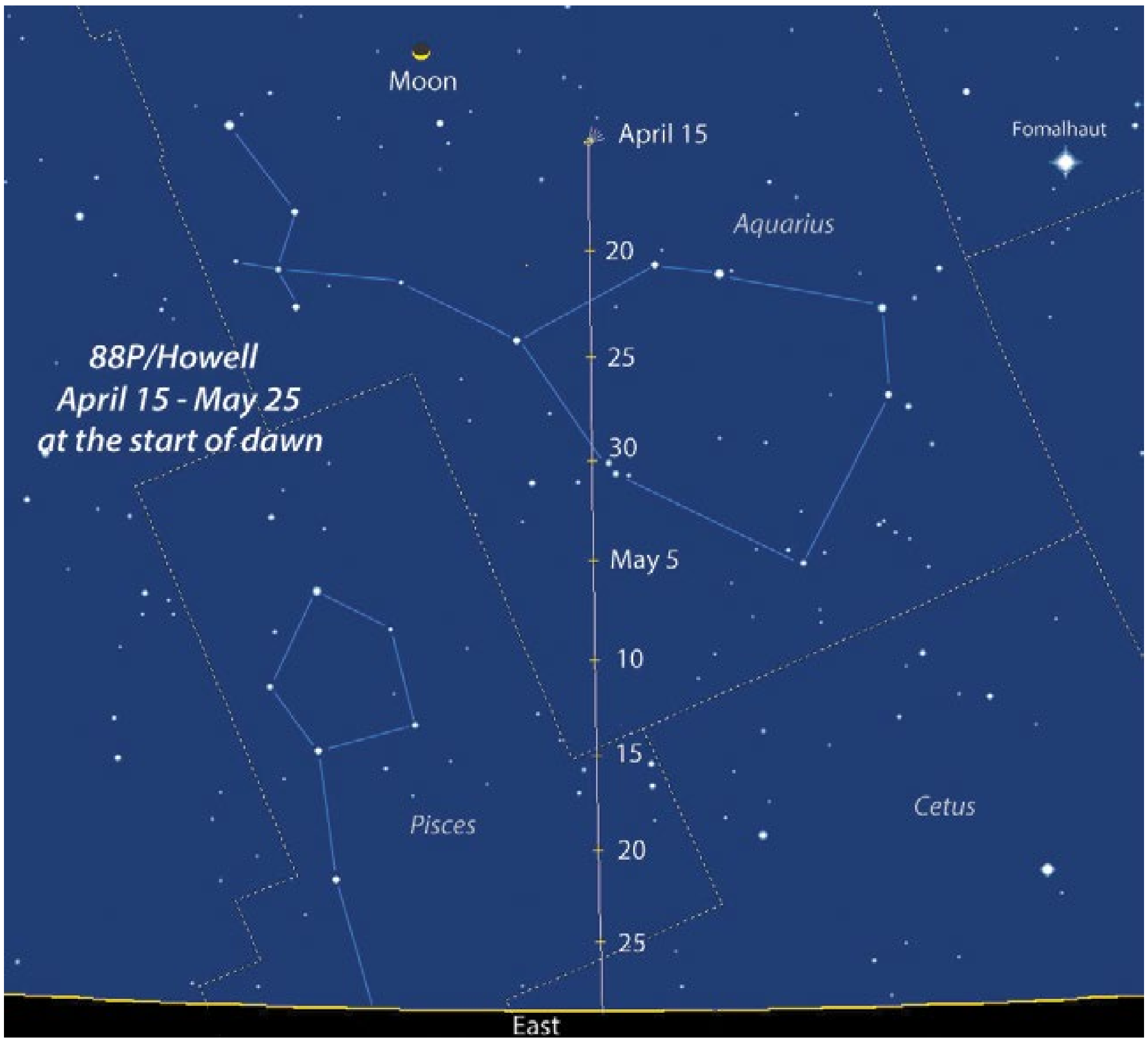
At the time of its discovery, the comet was close to four months past perihelion (closest point to the Sun) and no brighter than 15th magnitude or thereabouts. It was found to be moving in a short-period elliptical orbit of just under six years in length – previously it had orbited the Sun in a larger ellipse before passing only 0.6 astronomical units from Jupiter in 1978 and being diverted into the shorter orbit. It has since been observed in 1987, 1993, 1998, 2004 and 2009. This year's return is rather similar to that of 2004, when Comet Howell reached around magnitude 10 in April and May.

Perihelion in 2015 falls on April 6.25 at 1.36 a.u. The comet will be an early morning object for Southern Hemisphere observers during April. As the month begins, 88P will be located in Capricornus, close to the boundary of Aquarius, into which constellation it will move during the first week and remain throughout the rest of the month.

If its brightness behaviour is similar to that of previous returns, especially that of 2004, the comet should be around magnitude 10.5 at the start of April, possibly brightening slightly by the month's end.

Comet Howell will appear quite diffuse, so low power and a dark sky will definitely be an advantage in observing it. If you have a suitable eastern sky, a pair of large tripod mounted binoculars should show the comet to advantage... although don't expect anything too spectacular. ✦

Kevin Parker snapped 88P/Howell passing the Lagoon Nebula on January 31 this year. The comet is the small, greenish fuzzball to the left of the nebula.

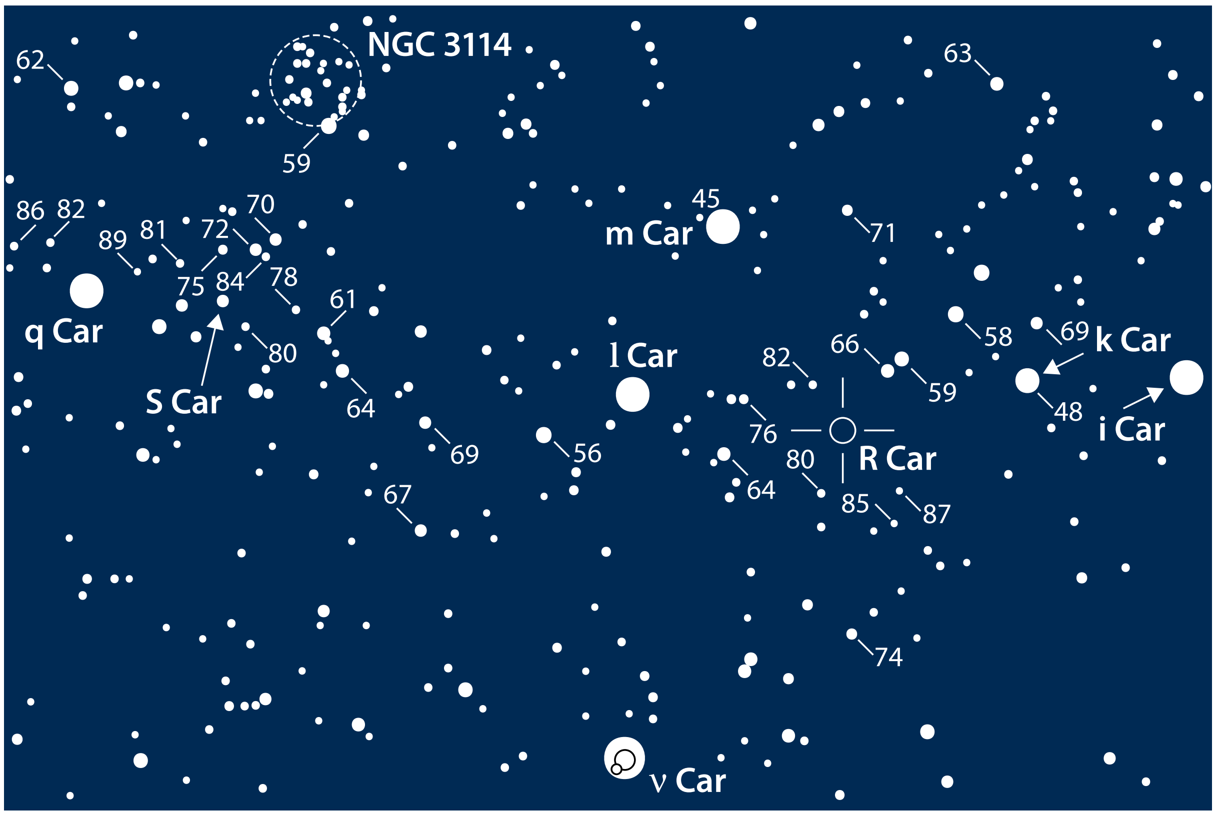


Comet 88P/Howell will put on a nice show around the start of morning twilight in the eastern sky as seen from the Southern Hemisphere. This graphic shows the view from Alice Springs; the Moon is shown for April 15. CHRIS MARRIOTT'S SKYMAP SOFTWARE

***David Seargent's* ebook *Sungrazing Comets: Snowballs in the Furnace* is available from Amazon.**

R and S Carinae

Alan Plummer



Finder chart for the long-period variable stars, R and S Carinae. North is up, and the chart is approximately 8.5 degrees in width. COURTESY OF THE AAVSO.

The long-period variable (LPV) stars R and S Carinae have historically been good ones to begin with when learning how to make variable star observations. Over time, as observers, if we add to our list of targets as we become more experienced, we can end up with a great many stars followed, some for extended periods of time. Peter Williams of Heathcote, NSW, has 45 years worth of data on S Car alone, and other variables too.

R Car is estimated to be about 416 light-years from Earth, and S Car about 1,320. According to the catalogues (comprising data gathered by amateurs, including of course Peter), R Car has a visual magnitude range of 3.9 to 10.5 over a period of 307 days, and S Car ranges over 4.5 to 9.9 in 149 days. As I write this, however, Andrew Pearce of the research group Variable Stars South, reports S Car's current cycle never got past ~6.5 mag, and others report the preceding minimum went below 10.0. To quote Andrew, 'LPVs are never boring'.

The finder chart above has been generated by the AAVSO Variable Star Plotter (VSP), with some added information. The numbers are visual magnitude to one decimal place, with the decimal points omitted because they would look like stars — so 65 is magnitude 6.5. The chart will be adequate for R and S Carinae when they're at maximum light, but you'll need to generate further charts from the VSP (www.aavso.org/vsp) if you want to follow them for the fainter halves of their cycles.

MAKE A CONTRIBUTION

Variable Stars South (VSS) has begun a visual observing project on the stars R and eta Carinae, that's suitable for beginners and experienced people alike. The VSS says the project observations will be added to historical data to extend the lightcurves of the two stars backwards in time as well as forwards, and the data will then be examined for any insights that can be gained into them. More details at: *http://www.variablestarssouth.org/projects/programmes/beginner-s-visual-observing*

Ross Gould
Double Star Notes

Sailing with the Argonauts again

Southern Pyxis and northern central Vela

Our region this month is in the old constellation Argo, the ship of Jason and the Argonauts who went in search of the Golden Fleece. Argo was broken up into smaller parts in the 19th century, and here we'll study an area in southern Pyxis (the mariner's compass, previously Malus, the mast) and northern Vela (the sails), along the ragged edge of the Milky Way.

Starting in northernmost Vela, our first destination is the bright **DUN 70**, located about 4º NE from 2nd-magnitude Gamma Velorum, itself a showpiece object. DUN 70 has stars of 5th and 7th magnitudes, and with a separation similar to Alpha Crucis it shows well in an 80mm refractor. Hartung described the colours as "pale and deep yellow"; I saw it as white and off-white, closer to the spectral types. It's a fine bright pair, standing out in a field that includes a small cluster (**vdB-Ha34**) to the north-east, and within the gaseous loops of the Vela Supernova Remnant.

From DUN 70, 3º north is **I 313**, a rather nice pair despite being absent from popular observing guides. The orange, magnitude 6.8 primary star has a small companion (mag 9.6) that was easily seen at only 100× through an 18-cm refractor; a 10-cm telescope should separate the stars, though perhaps needing more magnification. The secondary star is itself a double (RST 2563), discovered in 1933 by Richard Rossiter with a 69-cm refractor, and too dim to be accessible to most amateur scopes (mags 9.6 and 13.6 at 2.4" separation).

Some 2.5º north from I 313 is the fine triple star **HJ 4107**, another 4" double, this time with 6th- and 8th-magnitude stars, plus a wider magnitude 9 companion. There's a colour-contrast between the white primary and dullish bronze secondary star, with the wider companion ashy-brown in nice contrast, as seen with an 18-cm refractor at 100×. A little way west in the field is a north-south line of three bright stars, and to the east another bright one; a good setting for a fine object. An aperture of 10-cm should show it adequately.

I 195 is 1.5º NNE from HJ 4107, or 2.5º SSW of **Beta Pyxis** (magnitude 4.0). It's been relatively fixed since Robert Innes discovered it in 1897 with a 7-inch refractor, the same size of telescope I used. At 100× it was a bright, deep yellow/orange star in a pleasing starry field, with a hint of the companion; at 180× the companion was a small point of light outside the diffraction ring of the primary. At only 1.9", this one might be too difficult with 9- to 10-cm scopes, because the secondary star, 2.3 magnitudes less than the magnitude 6.6 primary, will sit on the first diffraction ring. With 12-cm the secondary will be on the outer edge of the ring. Remember that good seeing conditions matter more with unequal pairs like this, and I 314 (below), than for equally bright doubles.

Our next double, **COO 74**, is about 5º south from Beta Pyx. This is another uneven double, magnitudes 5.2 and 9.1, but easier than I 195 because of twice the separation at 4". It gave a delicate effect with a 15-cm refractor at 75×, a bright yellow star with a small close companion. And 15' south-west of COO 74 is the much more difficult double **B 1623**, discovered in 1929 by Willem van den Bos using a 67-cm refractor. This is a tight pair of magnitudes 7.5 and 8.9, at 0.7", so a larger scope is preferred. COO 74 sits on the eastern edge of a broad cluster (RU 64) about a degree across.

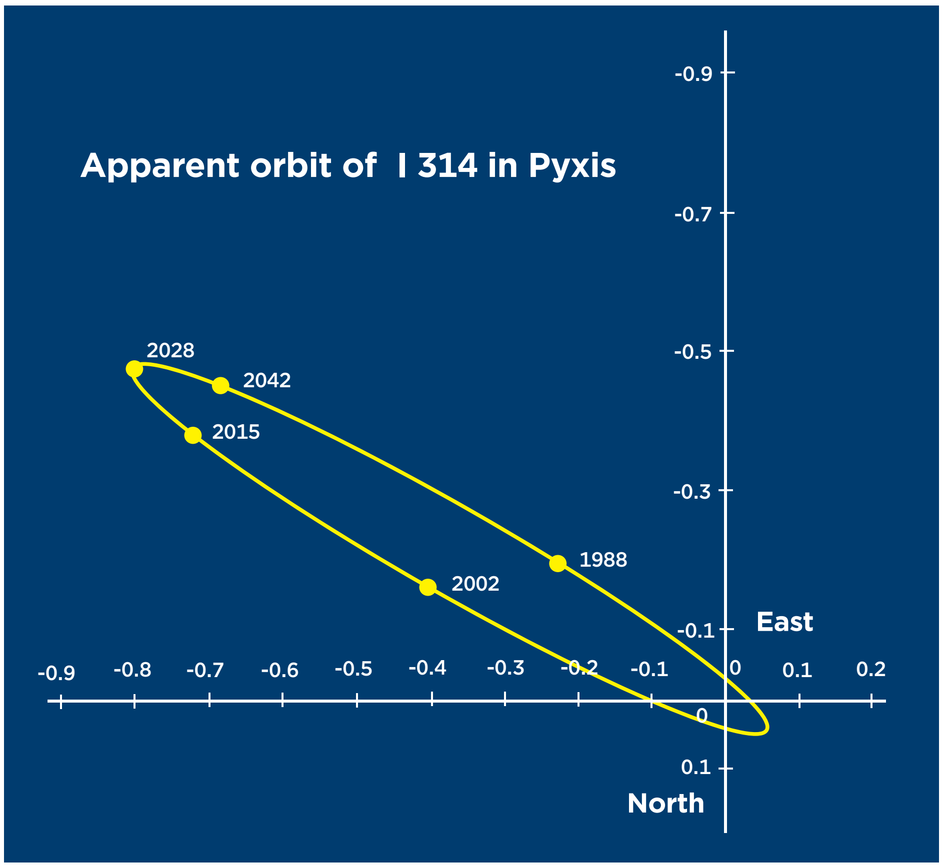
From COO 74, some 2.5º SSE is a field that includes two doubles and a small open cluster. The doubles were mid-19th century discoveries by Captain William Jacob, about whom I wrote in the January 2014 AS&T. The fainter of them is the wider - **JC 14** is an even pair, magnitudes 8.6 and 8.7, a bit over 5" apart. It was easy through a 18-cm refractor at 100×. Increasing the power to180× showed **JC 13** as a tight uneven pair, magnitudes 7.2 and 9.2 stars at a separation of 2.2". The bright stars of the little cluster **TR 10** are east and north of the doubles. The large nebula **GUM 17** is immediately east of the cluster.

We'll now cross the border, northwards into **Pyxis**. The triple star **HJ 4106** is found 2.3º south-west of Beta Pyx. Though not a bright combination, it was quite attractive through the 18-cm refractor at 100×.

Doubles of Pyxis and Vela

Star Name	R. A. hh mm	Dec. ° ′	Magnitudes	Separation (arcseconds)	Position Angle(°)	Date of Measure	Spectrum
DUN 70	08 29.5	-44 43	5.2, 7.0	4.3″	349	2002	B2IV, B2.5V
I 313	08 30.8	-41 31	6.8, 9.6	3.6″	214	1991	K1III
HJ 4107	08 31.4	-39 04	AB 6.5, 8.2	4.3″	330	1999	B4V
″	″	″	AC 6.5, 9.1	30.1″	099	1999	
I 195	08 34.5	-37 37	6.6, 8.9	1.9″	042	1991	K5III
COO 74	08 40.3	-40 16	5.2, 9.1	4.1″	066	1999	B9V
B1623	08 39.2	-40 25	7.5, 8.9	0.7″	255	2008	O9III
JC 13	08 46.6	-42 34	7.2, 9.2	2.2″	311	1991	B3III/IV
JC 14	08 47.3	-42 36	8.6, 8.7	5.4″	086	1999	B8/9 IV/V
HJ 4106	08 31.4	-36 42	AB 7.9, 9.9	4.4″	305	1999	K1IV
″	″	″	AC 7.9, 10.4	47.7″	219	1999	
TDS 5875	08 29.9	-36 38	11.6, 12.5	3.0″	079	1991	
TDS 5881	08 30.4	-36 39	11.2, 12.1	2.5″	004	1991	
I 314	08 39.4	-36 36	6.4, 7.9	0.8e	242e	2015	F1IV

Data from the *Washington Double Star Catalog*



The main pair, magnitudes 7.7 and 9.7, are 4" apart and there's a wide third star of magnitude 10.7. The primary is orange-yellow. Just west in the field is a north-south asterism, including a wide, curved triple star. Two dim little pairs are in the asterism, each with 12th-magnitude stars, separated by 2.5" **(TDS 5881)** and 3.0" **(TDS 5875)**. The primary of TDS 5875 is the third star of the curved broad triple. These dim pairs are offered for observers with larger scopes.

And 1.25° south from Beta Pyx is our feature binary this month, **I 314,** another of the many southern doubles of Robert (RTA) Innes, whose discoveries numbered 1,608 in total. I 314 was first observed and measured in 1900, with the 18-inch McClean visual refractor at the Cape Observatory in South Africa. It was near maximum separation at the time. Measures since 1900 have allowed an orbit calculation; the period is 66.5-years, and separation ranges between almost 1.0" and less than 0.1".

The pale yellow stars of I 314 are of magnitudes 6.4 and 7.9, and it's currently in the wider part of the orbit. One might expect that a fairly bright binary, with much of its orbit at nearly 1" separation, would be listed in observing guides. But that's not the case, and I 314 is absent from *Hartung's* and *Haas*, and not marked double in the *Cambridge Double Star Atlas*; however the *Uranometria* atlases, 1st and 2nd editions, do show it as a double. So it's an overlooked double, although not neglected, as the *Washington Double Star Catalog* notes 29 measures of it.

As recently as the 1990s, I 314 was inaccessible to amateur scopes, being below 0.3" separation for most of that decade, then gradually widening to 0.5" in 2004, and just over 0.8" in 2015. From 2020 until 2035 it will be at 0.9" or just over, then gradually close up again, the closest part of the orbit being in the 2050s. I 314 is just over 120 light-years from us, and the projected size of the orbit, as seen from Earth, stretches to about 35 a.u. separation, similar to the size of the 80-year orbit of Alpha Centauri. Because of much greater distance from Earth than Alpha Cen, I 314 is a much closer and consequently more-difficult pair for observation.

When observing I 314, if your telescope is around 20- to 23-cm aperture, the companion will be on the primary's first diffraction ring; with 28-cm the secondary should be on the outer edge of the diffraction ring. The brightness difference here is 1.5 magnitudes so it shouldn't be completely lost in the first diffraction ring, unless your scope has a very large central obstruction. Refractors, unobstructed and therefore with fainter diffraction rings, have the advantage. The present separation matches the Rayleigh Criterion for 17-cm aperture. I'd expect I 314 to be seen in various ways with scopes in the 17- to 25-cm range. I'd like to hear from you about your observing experience of I 314. ✦

Ross Gould **has been a long-time double star observer from the suburban skies of Canberra. He can be reached at rgould1792@optusnet.com.au**

Sue French
Targets

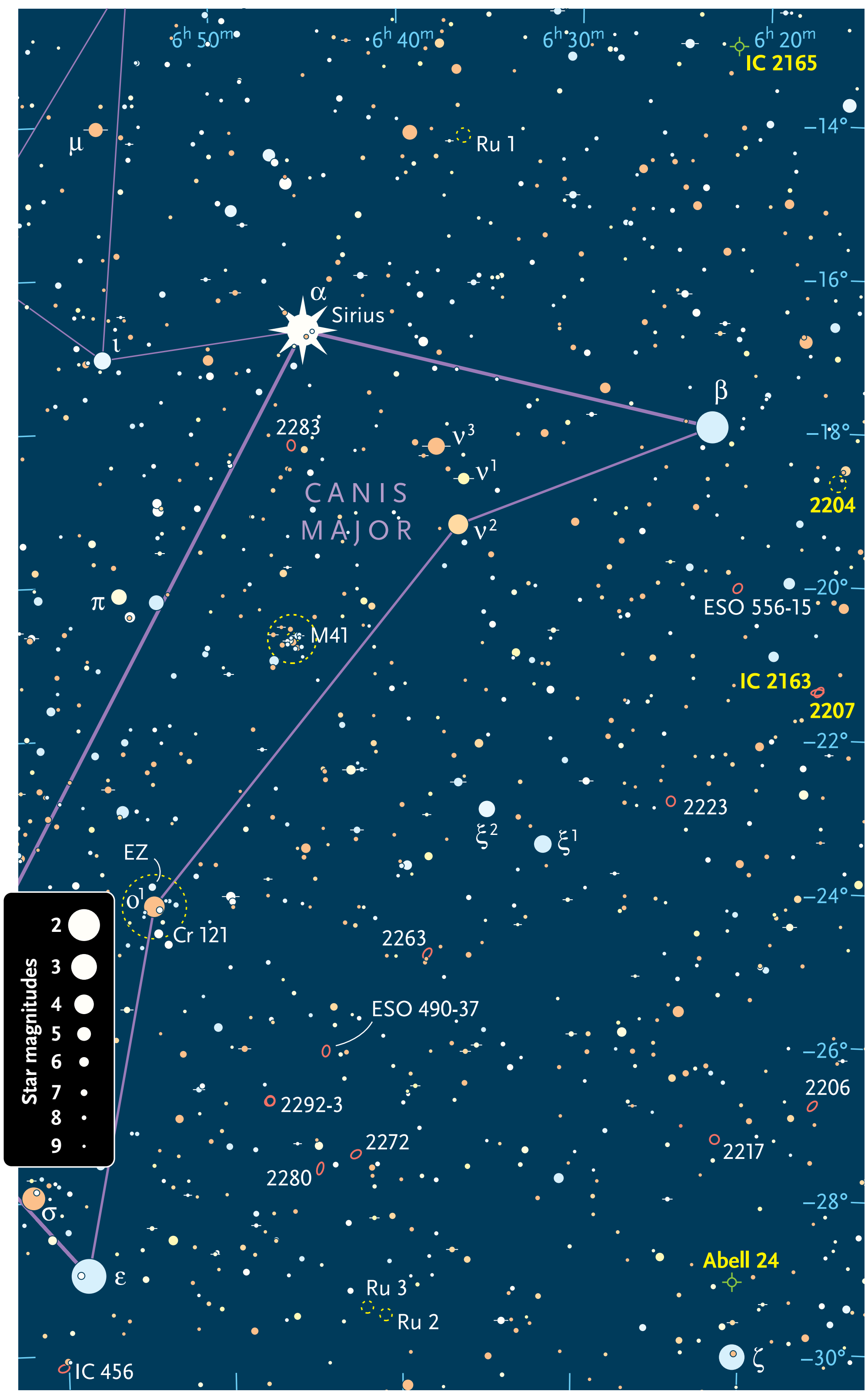
Going to the Dogs

Spend an evening out with our canine companions.

I've always loved canines, so going to the dogs sounds pretty good to me, either here on Earth or in the night sky with Canis Major and Canis Minor.

Canis Minor gets short shrift when it comes to attention. The Little Dog hosts few bright stars or deep sky wonders to draw us its way. Yet there are some worthy of homage if you know where to look.

One of the most interesting for small-scope enthusiasts is the possible open cluster, the **ADS 6366 Group**, also known as Herschel 1. On December 20, 1827, John Herschel swept up the multiple star at the heart of the group. He noted that it was "in a small cluster of 8 stars," which he sketched.



Despite its early discovery, the ADS 6366 Group was not specifically cataloged until 2003, when Brent A. Archinal and Steven J. Hynes included it in their book, *Star Clusters*. The cluster was brought to the author's attention by Brian Skiff of Lowell Observatory, who noticed the group observationally as a possible cluster in 1988. More recently, Skiff determined that the group's bluer stars could be related physically.

Through my 130-mm refractor at 23×, I see four stars in a curvy line and a brighter star to the south. Boosting the magnification to 164×, there are six stars in the curve, looking much like the distinctive bend of seagull wings in flight. The bright star nearby could be the bird's head, and two more stars to its west complete the gull's body. This charming group spans 4.2′, wingtip to wingtip. My 25-cm reflector at 299× reveals a dozen stars gathered into a shape that resembles a double-convex lens.

Steve Gottlieb introduced me to a curious asterism at the western edge of Canis Minor that he calls the **Triple Trapezoid**, "a small group of 6 stars that essentially forms three nearly isosceles trapezoids!" Two small trapezoids use the same two stars to make their narrow tops, while their four base stars also form a larger trapezoid encompassing all.

The exterior trapezoid is easily visible through my 130-mm scope at 63×, and at 117× one of the interior stars appears. Although the final star is glimpsed at 164×, I need 273× to hold it steadily in view. The Triple Trapezoid is readily seen with my 25-cm scope at 171×, but one of the interior stars is considerably dimmer than the rest. The exterior trapezoid's base is only 1.6′ long.

Objects in Canis Major and Canis Minor

Object	Type	Mag(v)	Size/Sep	RA	Dec.
ADS 6366 Group	Possible cluster	7.5	1.9′ × 1.8′	7h 47.0m	+00° 01′
Triple Trapezoid	Asterism	—	1.3′	7h 10.8m	+06° 00′
Abell 24	Planetary nebula	13.5	2.5′ × 1.1′	7h 51.6m	+03° 00′
IC 2165	Planetary nebula	10.6	9′ × 7′	6h 21.7m	–12° 59′
NGC 2204	Open cluster	8.6	16′ × 12′	6h 15.6m	–18° 40′
NGC 2207 & IC 2163	Galaxy in pair	11	4.3′ × 2.8′	6h 16.4m	–21° 22′
Sharpless 2-308	Wolf-Rayet shell	—	41′	6h 54.4m	–23° 56′
Douglas's Triangle	Asterism	—	9′	7h 05.6m	–26° 13′

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Canis Minor contains three Abell planetary nebulae, which were discovered in the 1950s and 1960s by George O. Abell, Albert G. Wilson, Robert G. Harrington and Rudolph Minkowski. So far, the only one that I've seen, and I use the term lightly, is **Abell 24**, located 1.2° due north of Zeta (ζ) Canis Minoris.

With my 25-cm reflector at 90×, all I can see of Abell 24 is two little, east-west spots about 2¼′ apart. Neither can be steadily held in view. My 37.5-cm scope at 79× fares a bit better. The nebula seems large, extremely faint and possibly annular. Adding a narrowband nebula filter changes the appearance, and I just get a sense of two ghostly patches northeast and southwest of each other. Images of Abell 24 show that each observation has some merit, showing different parts of Abell 24's complex structure.

Let's now segue from the realm of the Little Dog to that of his big brother, starting with a different sort of planetary nebula. Tiny and bright, **IC 2165** resides in the northwestern corner of Canis Major. Although it's a minuscule dot through my 105-mm refractor at 36×, IC 2165 is recognisable as a planetary nebula by its blue-grey colour. At 122× it remains bluish and wears a fainter fringe. The nebula holds its colour even at 320× through my 25-cm scope and looks slightly oval with a small, somewhat darker centre.

Descriptions of this planetary seem to vary quite a bit among observers. What do you see?

A tenant of the Astronomical League's Herschel 400 observing program, **NGC 2204** is an open cluster found 1.8° west-southwest of Beta (β) Canis Majoris. Through my 105-mm refractor at 17×, I see a misty glow with a 10th-magnitude star on the west-southwestern edge and a 9th-magnitude star closely guarding the north-northwestern edge. A magnification of 87× pries 18 dim stars (magnitudes 12 and 13) out of the haze. NGC 2204 morphs into a rich group of about 40 faint to extremely faint stars when viewed with my 25-cm scope at 220×.

NGC 2204 is a senior citizen among open clusters, being about 2.6 billion years old. Most open star clusters don't last more than a few hundred million years before their constituent stars disperse.

We don't often think of Canis Major as a place to observe galaxies, but a classic interacting duo dwells 2.7° south of NGC 2204. NGC 2207 and IC 2163 are clearly visible as a single oval glow through my 105-mm scope at 28×. At 87× they look quite strange. Their halos are blended together, making a southeast-northwest oval with a bump on its eastern side. The combined glow has a brighter core that seems offset to the west, while careful study shows a very subtle brightening within the bump. A faint star sits just beyond the northwestern tip of the pair, while another hangs 2′ south of the core. With my 25-cm scope at 118×, it's more obvious that there are two galaxies here rather than one peculiar galaxy. NGC 2207, the owner of the more obvious core, is about 2′ long and two-thirds as wide. IC 2163 appears roughly 1½′ long east-west and only half as wide.

Next we'll slide down to the yellow-orange gem Omicron^1 (o^1) Canis Majoris, which is pinned to the edge of the Wolf-Rayet shell **Sharpless 2-308**. This cosmic bubble was formed when fierce winds from the intensely hot star, EZ Canis Majoris, seen near the shell's centre, plowed into slower-moving material shed earlier in the star's history.

A small group of six stars forms the butterfly-like asterism Triple Trapezoid at the western edge of Canis Minor. POSS-II / ST SCI / CALTECH / PALOMAR OBSERVATORY

Don Goldman enhanced the faint nebulosity of Sh 2-308 with O III and Hα filters. The orange supergiant, Omicron[1], burns at the right edge of the Wolf-Rayet shell.

> **"With the help of an O III filter, much of the nebula's patchy rim is visible even through a small scope – think of a more gauzy version of the Veil Nebula in Cygnus."**

Sh 2-308 looks so delicate in photographs that you might think it's an impossible visual target. But with the help of an O III filter, much of the nebula's patchy rim is visible even through a small scope. When looking for it, think of a more gauzy version of the Veil Nebula in Cygnus.

I enjoy seeing Sh 2-308 with my 105-mm refractor. A magnification of 28× works well, showing a smoky ring about 40′ across and 4′ wide at most. The brightest section starts near Omicron[1] and curves up toward the west while passing through the northeastern half of a skinny, 10½′-tall kite made by four fairly bright stars. It fades in the northwest just a bit after skirting outside a 9th-magnitude star, then starts to show up again in the north-northwest. This dimmer section continues to the northeast where it pretty much disappears. It then picks up again in the south-southeast to return full circle to Omicron[1].

For the March 1999 issue of the US edition of *Sky & Telescope*, Roger Sinnott penned an article called *Hunting for Equilateral Triple Stars*, a pastime quite a few amateur astronomers pursue. In 2012 California amateur Robert J. Douglas wrote to me about a remarkably compact one with sides only 9″ long. **Douglas' Triangle** rests 39′ west-northwest of Delta (δ) Canis Majoris. Look for it 2.8′ north of the western of two golden, 8.8-magnitude stars 2.3′ apart. Through my 25-cm scope at 213×, this petite triangle is a cute sight, with stars of about 11th and 12th magnitude. Give it a try! ✦

Composed of 11th- and 12th-magnitude stars, the modest Douglas' Triangle presents a rewarding challenge for observers. POSS-II / ST SCI / CALTECH / PALOMAR OBSERVATORY

Sue French **welcomes your comments at scfrench@nycap.rr.com.**

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Powering Up

Choose the right magnification for your planetary observing experience.

For planetary observers, selecting the optimal magnification requires striking a delicate balance between the size and sharpness of the image while preserving sufficient image brightness.

A minimum magnification is required for the human eye to fully exploit the resolving power of any telescope. Most sources cite a rather modest value of 13× per inch of aperture that was derived from studies that used test charts of very high contrast — black markings on a white background. (We'll stick with inches rather than centimetres for apertures in this article, for historical reasons.) Of course, the contrast of most planetary markings is far more subdued. When low-contrast test charts that closely mimic planetary subjects are employed, this value increases by a factor of two or even three, corresponding to at least 26× to as much as 39× per inch of aperture. If we use the latter figure, to fully exploit the resolving power of a 4-inch telescope requires a magnification of 156×, while a 16-inch telescope requires no less than a whopping 624×.

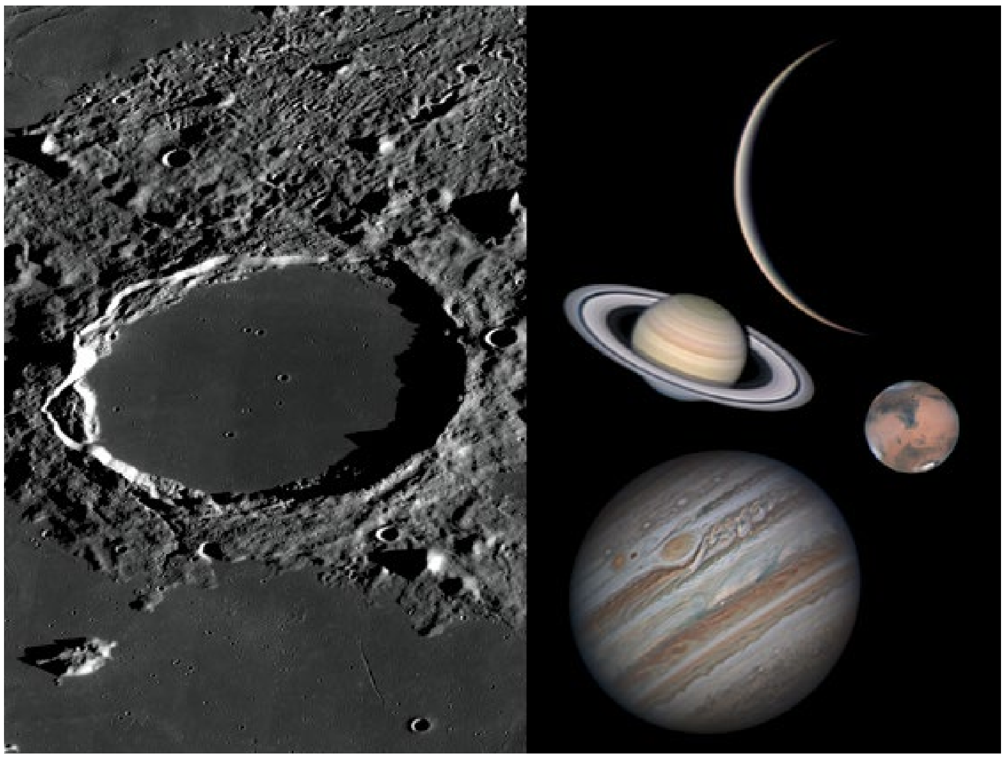
Provided that a telescope has sufficient optical quality, the single most important factor in determining the clarity of the planetary images that it will deliver is the tranquility of the Earth's atmosphere. "The atmosphere," lamented the French astronomer André Couder, "is the worst part of the instrument." 'Seeing' is caused by turbulent air cells at altitudes ranging from several hundred metres to 15 kilometres that have different temperatures and hence different indices of refraction. At most observing sites these atmospheric cells usually range in size from 10 to 20 centimetres in diameter, although research by atmospheric physicists has revealed that they can vary tremendously in size. Each cell acts as a lens, changing the focal position of the image by bending incoming rays of light differently.

If the aperture of a telescope is large enough to receive light that has passed through many air cells, a blurred, 'washed-out,' or 'boiling' image will result. But when the aperture of a telescope is approximately the same diameter as the air cells, the image will be well defined, although sharpest focus may change as individual cells drift across the light path.

The larger the aperture of the telescope, the smaller the probability that the air mass over it will be optically homogeneous at any given moment. When it comes to resolving planetary details, telescopes of modest aperture (from 8 to 10 inches in diameter) are disproportionately efficient compared to large instruments, resolving to their theoretical limits on a far greater number of nights. In 1885, the American astronomer Asaph Hall remarked: "There is too much scepticism on the part of those who work with large instruments in regard to what can be seen with small ones."

The remarkably high efficiency of modest-aperture telescopes is accurately reflected in a five-decade-old formula devised by the German planetary observer Günter Roth. According to Roth, the maximum practical magnification for planetary observing corresponds to 140 multiplied by the square root of the aperture in inches, as tabulated below.

Aperture inches (cm)	Maximum useful magnification	Power per inch
4 (10)	280×	70×
6 (15)	343×	57×
10 (25)	443×	44×
16 (40)	560×	35×
24 (60)	686×	29×
36 (90)	840×	23×



Shown here to approximate scale, the planets never appear as large as the lunar crater Plato. Seeing detail on the planets requires high magnifications, but how high is too high? PLATO: NASA / GSFC / ARIZONA STATE UNIVERSITY, PLANETS: SEAN WALKER

The experience of Edward Emerson Barnard, the preeminent American planetary observer of the 19th century, lends credence to Roth's formula. According to Barnard, the best planetary images through the 36-inch Lick refractor were obtained with magnifications of 360× to 540× (10× to 15× per inch of aperture), with no improvement beyond 1000× (28× per inch of aperture) even on exceptionally steady nights.

Barnard's contemporary, the Greco-French astronomer Eugène Antoniadi, also preferred to use comparatively low magnifications with the 33-inch Meudon refractor at the Paris

Observatory. His best views of Mars and Jupiter were obtained with magnifications of only 320× to 540× (10× to 16× per inch of aperture).

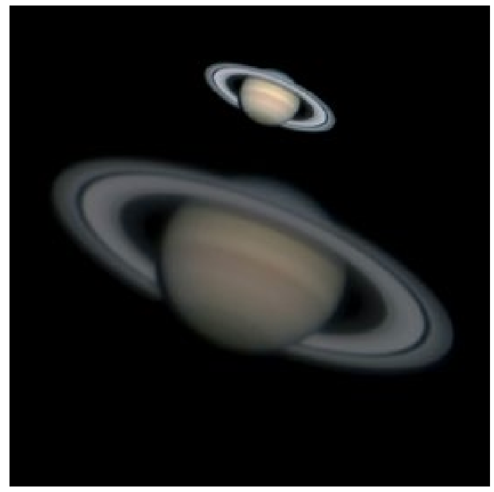
If large telescopes are so handicapped by atmospheric turbulence that they usually fail to resolve details beyond the capabilities of a 12- to 16-inch aperture, why do they often deliver more revealing views of the planets than smaller instruments? The answer lies in image brightness, which is essential for perceiving subtle differences in both tone and hue.

The luminances (apparent brightness per unit area) of the planets compared to the full Moon are shown in the table below:

Full Moon	1.0
Mercury	5.8
Venus	9.6
Mars	0.55
Jupiter	0.15
Saturn	0.045
Uranus	0.013
Neptune	0.005

With large apertures, the excessive surface brightness of the Moon, Venus and Mars results in troublesome glare that must be reduced using neutral density or colour filters. However, the apparent surface brightness of Jupiter is only one-third that of Mars, and the apparent surface brightness of Saturn is in turn only one-third that of Jupiter. The features of the gas giants consist of a palette of delicate pastel hues of rather modest contrast. Jupiter's belts and zones typically differ in apparent brightness by 10% to 20% percent, while the contrast of Saturn's belts and zones, muted by the presence of high-altitude atmospheric hazes, usually amount to only 5% to 15%. If the image is large but dim, it becomes difficult to perceive subtle differences of contrast and color.

The leading British Jupiter observer of the late 19th century, William Frederick Denning, was equipped with an excellent 12.6-inch Newtonian reflector. He found that magnifications of 205× and 225× gave superb definition but images that were too small. The best power for Jupiter (and planetary observing in general) proved to be 315×, while 404× and 450× offered no advantage except on the very best nights. Denning's results are representative of the general consensus that has emerged among experienced planetary observers.



Doubling magnification reduces the apparent surface brightness of an extended object such as a planet by a factor of four. Too large an image scale also dilutes colours and washes out low-contrast features. This pair of Saturn images above simulates the problem and really drives home the notion of 'empty magnification.' SEAN WALKER

The old Roman axiom *De gustibus non es disputandum* ("In matters of taste there can be no disputes") certainly holds true when it comes to magnification. Individual differences in visual acuity and even temperament play a role. Some observers prefer to use comparatively high magnifications even under rather adverse seeing conditions, waiting patiently for any fleeting moments when the seeing momentarily improves.

The selenographer Johann Heinrich von Mädler was an extreme example of the 'wait it out' school. He routinely used 400× with his 4-inch Fraunhofer refractor when observing the Moon to produce (in collaboration with Wilhelm Beer) *Mappa Selenographica* and the first decent map of Mars.

On the other end of the spectrum was the keen-eyed Philipp Fauth, one of the leading German lunar and planetary observers of the early 20th century. Fauth usually employed magnifications of only 25× per inch with his 6-, 7-, and 15-inch refractors, reserving the highest magnifications of only 38× per inch only for the finest nights. "Sharpness is more important than image scale," he wrote. Every observer has his or her own personal equation, and it may change over the years. ✦

Alan MacRobert
TOTAL ECLIPSE

A barely total lunar eclipse

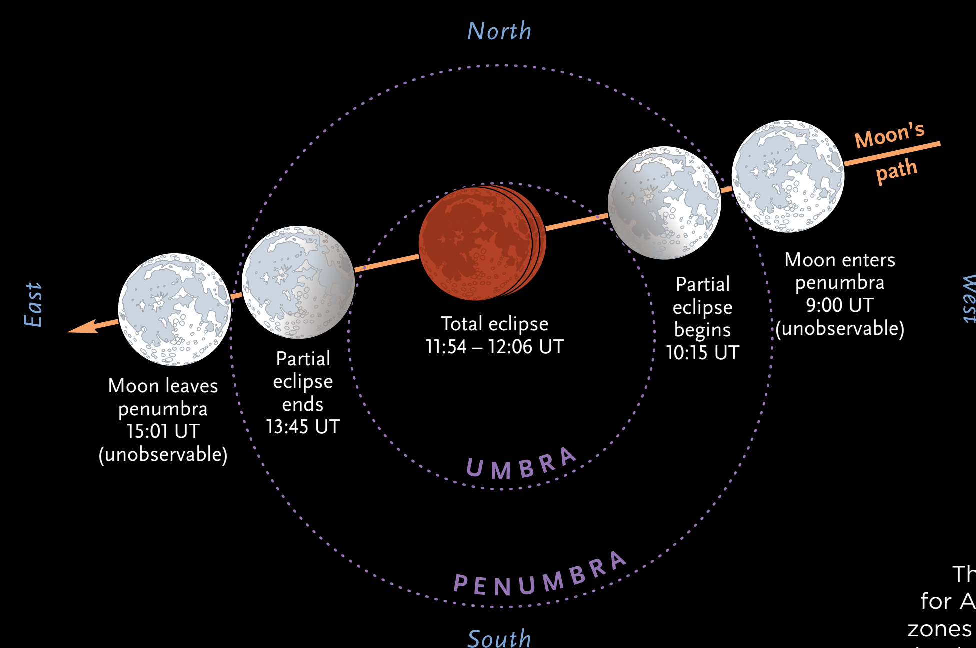
On the morning of April 4th, the Moon skims just inside Earth's umbra.

The next total eclipse of the Moon will greet evening stargazers on Saturday, April 4. It will be the third in the current tetrad of total lunar eclipses coming at half-year intervals.

This eclipse will be just barely total and last for only about 10 minutes. You may even get the impression that it never becomes quite total at all. The Moon's north-northeastern limb will be so slightly inside the umbra (the central portion of Earth's shadow) that it will remain much brighter than the deep red we can expect across the rest of the Moon's face.

If you're in New Zealand, the event happens deep in the night and high in the sky. For Australia, it occurs in the evening – those in the eastern half of the continent will see the whole thing, while for those in the west the eclipse will be underway as evening twilight begins.

Total Eclipse of the Moon, April 4, 2015



The times listed for Australian time zones below do not take daylight savings into account.

Eclipse event	UT	EST	CST	WST
Partial eclipse begins	**10:15.4**	**8:15 p.m.**	**7:45 p.m.**	**6:15 p.m.**
Total eclipse begins	**11:54.1**	**9:54 p.m.**	**9:24 p.m.**	**7:54 p.m.**
Mid-eclipse	**12:00.2**	**10:00 p.m.**	**9:30 p.m.**	**8:00 p.m.**
Total eclipse ends	**12:06.4**	**10:06 p.m.**	**9:36 p.m.**	**8:06 p.m.**
Partial eclipse ends	**13:45.1**	**11:45 p.m.**	**11:15 p.m.**	**9:45 p.m.**

Stages of the Eclipse

A total lunar eclipse has five stages, with different things to watch out for at each.

The penumbral stage begins when the Moon's leading edge enters the pale outer fringe of Earth's shadow: the penumbra. But the shading is so weak that you won't see anything of the penumbra until the Moon is about halfway across it. The penumbral shading becomes stronger as the Moon moves deeper in.

The second stage is partial eclipse. This begins much more dramatically when the Moon's leading edge enters the umbra, where no direct sunlight reaches. With a telescope, watch the umbra's edge engulf one lunar feature after another as the night around you deepens. Eventually just a final bright arc remains outside the umbra, while the rest is already showing a foreboding reddish glow.

The third stage is total eclipse, beginning when the last of the Moon slips into the umbra. But this depends on how the umbra's edge is defined! The edge is hazy, and in a grazing eclipse like this, its adopted definition is critical enough that the U.S. Naval Observatory's *Astronomical Almanac* lists totality as lasting 12.3 minutes, while Fred Espenak's *Fifty-Year Canon of Lunar Eclipses* says only 8.6 minutes, so take your pick.

Most of the Moon is sure to glow some shade of intense orange or red. The red light shining onto the Moon is sunlight that has skimmed and bent through Earth's atmosphere; it's from of all the sunrises and sunsets that ring our world at any given moment.

Two factors affect a lunar eclipse's colour and brightness. The first is how deeply the Moon goes into the umbra; the umbra's centre is much darker than its edges. The other factor is the state of Earth's atmosphere along the sunrise-sunset line. If the air is very clear, the eclipse is bright. But when a major volcanic eruption has recently polluted the stratosphere with thin global haze, a lunar eclipse will be dark red, ashen gray or occasionally almost black.

As the Moon continues eastward along its orbit, events replay in reverse order. The Moon's edge re-emerges into sunlight, ending totality and beginning stage four: a partial eclipse again. When all of the Moon escapes the umbra, only the last, penumbral shading is left for stage five. By about 45 minutes later, nothing unusual will remain at all. ✦

Best in Show

Take a tour of four top planetary nebulae visible in the autumn sky.

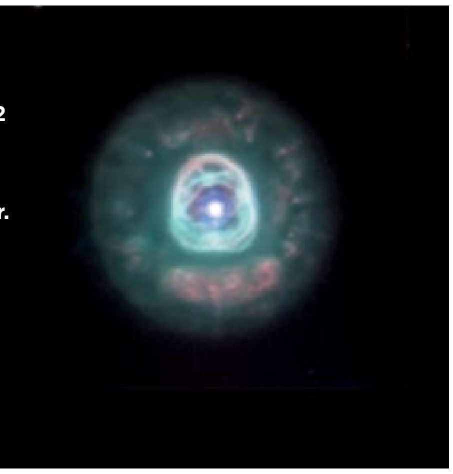
The autumn sky is home to several of the season's top planetary nebulae. These ephemeral celestial gas bubbles are among the most beautiful and fascinating objects in the sky. Many have a high surface brightness, making them excellent targets for small scopes and revealing a wide variety of structural features through larger instruments.

Most planetaries glow brightest in the greenish light of 5007 angstroms, emitted when oxygen is doubly ionised by ultraviolet radiation from the central star. As a result, an O III line filter or a narrow bandpass filter can dramatically increase the contrast, both from light-polluted locations and dark sites. When the seeing permits, remove the filter and pump up the magnification to search for small structural details.

William Herschel picked up **NGC 2392** in a January 1787 sweep, adding it to the list of "nebulous stars" spotted through his 18.7-inch speculum reflector. In a letter read before the Royal Society in 1791, he described it as "a star with a pretty strong milky nebulosity, equally dispersed all around; the star about the 9th magnitude." Through my 80-mm refractor at low power, NGC 2392 shows up as a fuzzy, bloated star about 2.5° southeast of 3.5-magnitude Delta (δ) Geminorum and less than 2′ south of an 8th-magnitude star. When I blink the planetary — quickly moving a filter in and out between the eyepiece and my eye — it flickers in brightness.

Through my 45-cm, the aqua-coloured nebula handles extreme powers beyond 800× in good seeing, and the double-shell structure is gorgeous. The 9th-magnitude central star is surrounded by a fairly narrow annulus, perhaps 20″ in diameter, with a darker central hole. A thin strip of darkness separates the inner portion from a 1′ outer halo (resembling a lion's mane or the hood of a parka), which is uneven in brightness.

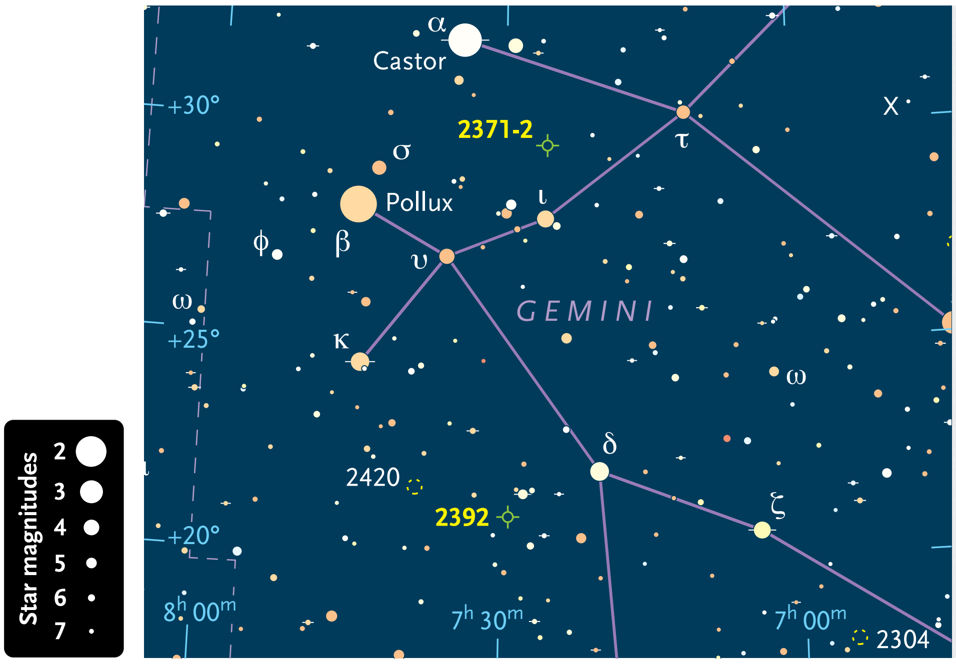
At high power through my 60-cm scope, the inner annulus is irregularly shaped and extends slightly farther to the north. This bulge has a slightly darker interior, producing a small pouch within the ring.

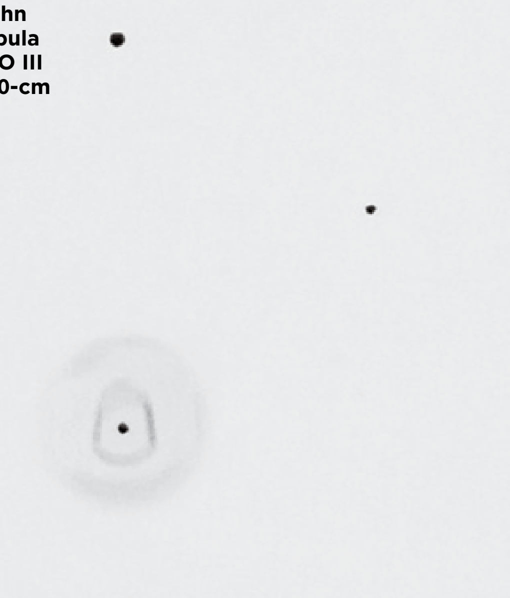


The central star glows bright in the turquoise nebulosity of NGC 2392 in this image taken during the Advanced Observing Program at Kitt Peak Visitor Center. S. KEMPTON & K. BRISTER / A. BLOCK / NOAO / AURA / NS

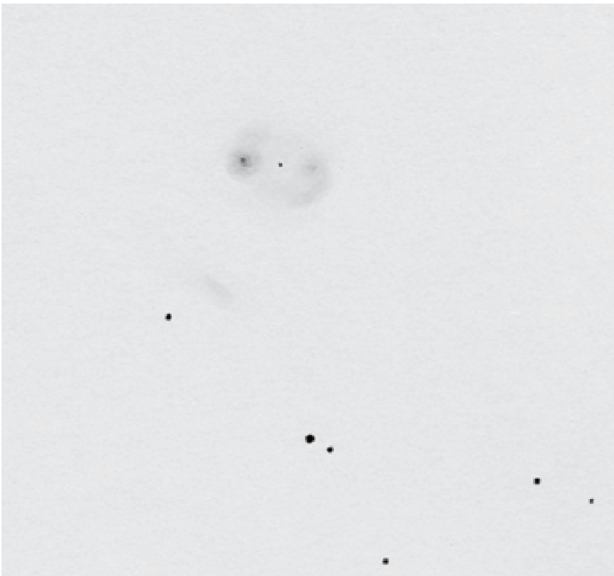
NGC 2371-72 is an excellent example of a bipolar planetary, with two symmetric lobes straddling a hot central star. William Herschel discovered this unusual planetary in 1785 with his 18.7-inch reflector. In his first *Catalogue of One Thousand New Nebulae and Clusters of Stars*, he reported it as a double nebula, resulting in two NGC designations.

A 10-cm scope will show a small, hazy patch 3° southwest of Castor, and an 20-cm will resolve Herschel's twin bubbles. Through my 45-cm, the bright lobes slant southwest to northeast and span 15″ to 20″ in



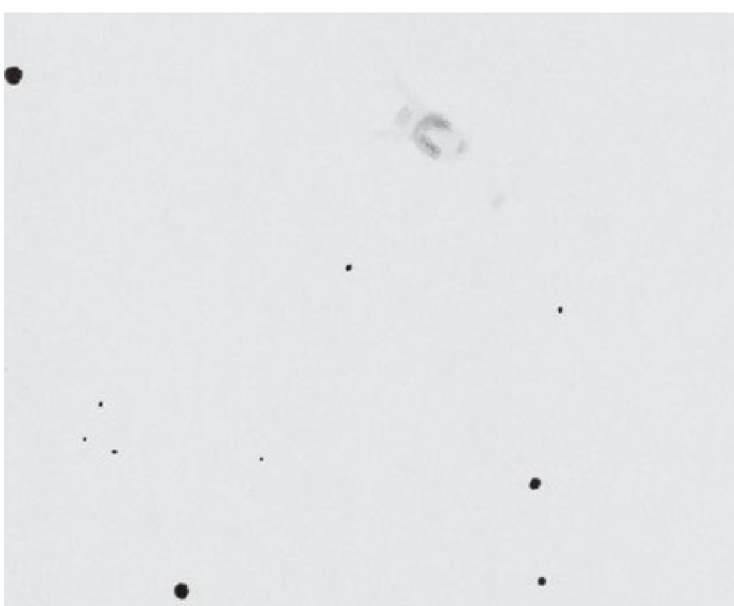


German stargazer Uwe Glahn sketched the planetary nebula NGC 2392 as seen with an O III filter at 600x through his 40-cm Dobsonian. ALL SKETCHES BY UWE GLAHN



Above left: **Uwe Glahn sketched NGC 2371-72 as seen through a 40-cm Dobsonian with an ultra-high contrast nebula filter at 280x.**

Above right: **Jim Misti's image, captured with a 80-cm Ritchey-Chrétien telescope, reveals the double 'polar caps' of NGC 2371-72.**

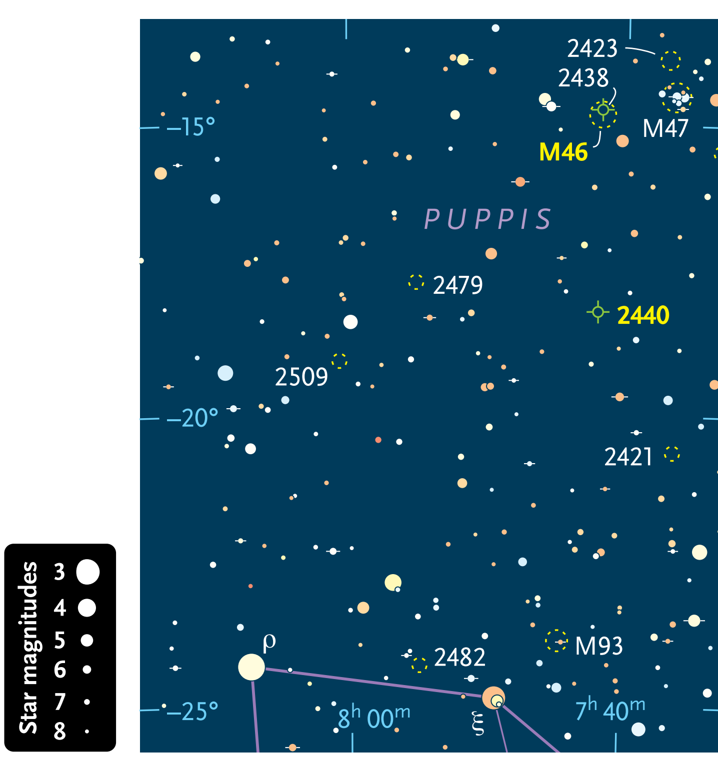


Left: **Uwe Glahn used an O III filter to draw out the features of NGC 2440 as seen through his 40-cm Dobsonian at 400x.**

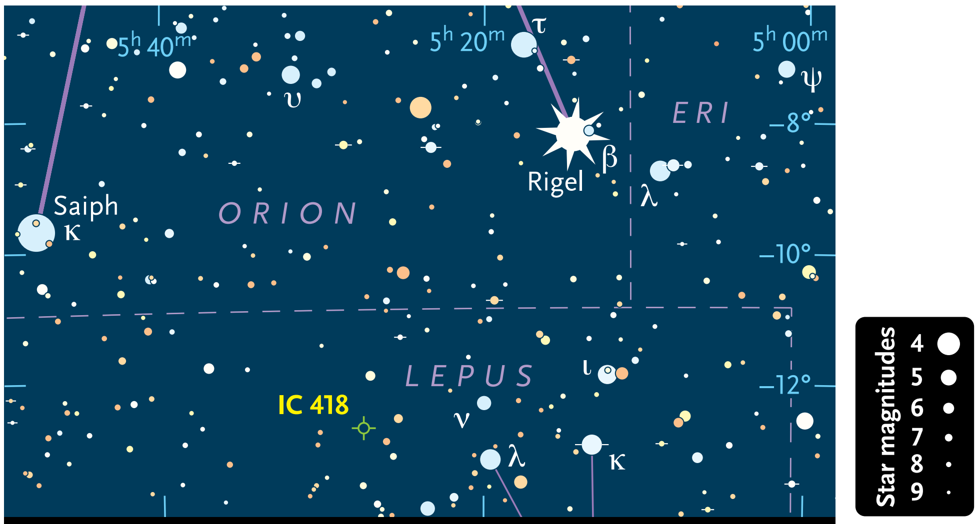
diameter. At 380× unfiltered, the southwest lobe appears brighter, the 15th-magnitude central star glowing dimly at the midpoint. A weak bridge of nebulosity connects the two lobes, and an ethereal halo encases the structure. Through my 60-cm, two detached ghostly 'polar caps,' or *ansae*, can be glimpsed 1′ northwest and southeast of the central star.

Four years ago, I viewed this planetary through Jimi Lowrey's 120-cm super-sized Dobsonian. At 488× magnification, the nodules varied in surface brightness and shape; both were adorned with filamentary wisps, as if they were revolving about the central star. The outer symmetrical caps each extended 40″ × 10″ and floated like two graceful wings around the central orb.

NGC 2440, located 3.4° due south of M46 in Puppis, has an unusually complex morphology. When William Herschel reported his March 1790 discovery, he described it as a "beautiful planetary nebula, of a considerable degree of brightness," but noted that it was "not very well defined." Deep images reveal an irregular, bow-tie shape with central condensations, radial filaments, gas blobs, and a second pair of butterfly wings. The central white dwarf



Below: **Hubble's Wide Field Planetary Camera brings the wings of NGC 2440 to full prominence.**



This false-colour image, composed from a series of photographs taken by Hubble's Wide Field Planetary Camera, displays the ionised oxygen as a blue ring around the central star.

Glahn observed IC 418 without a filter during a visit to Roque de los Muchachos, on the island of La Palma, Spain. This sketch shows his view at 900x through a 50-cm reflector.

Planetary Nebulae

Object	Cons.	Mag. (v)	Size	RA	Dec.
NGC 2392	Gem	9.1	47″ × 43″	7h 29.2m	+20° 55′
NGC 2371 -72	Gem	11.2	74″ × 54″	7h 25.6m	+29° 29′
NGC 2440	Pup	9.4	74″ × 42″	7h 41.9m	–18° 13′
IC 418	Lep	9.3	14″ × 11″	5h 27.5m	–12° 42′

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

radiates mostly in the ultraviolet (only 18th-magnitude visually) and is one of the hottest known stars, with a surface temperature of 200,000°C.

A 15-cm scope at 75× displays a small, hazy oval, 20″ to 25″ in diameter, with a relatively high surface brightness and a slight cyan tint. High power will resolve two compact knots near the center. Through my 45-cm at 380×, the bright, boxy inner region contains two condensations. A fainter halo extends 2:1 southwest to northeast, though it's weaker on the southwest end, forming a cup-shaped dark notch. Two outer wings, mimicking spiral arms in a galaxy, extend northwest and southeast.

Through Lowrey's 120-cm, the irregularly-shaped central region harbours three intense knots; the ragged periphery appears tattered, as if the object had exploded. A prominent wing attached on the northwest edge swings clockwise to the west and a large, outer loop spans the entire eastern end.

According to Harvard College Observatory records, **IC 418**, also known as the 'Spirograph Nebula,' was spotted first by Williamina Fleming while she was working as an assistant to Edward Pickering, then director of the observatory. IC 418 is a young, carbon-rich planetary in Lepus that flaunts an interlaced network of filaments in the Hubble Space Telescope image. To locate IC 418, drop 4° south of Rigel to a trapezoid-shaped group of 4th- and 5th-magnitude stars. Our target is 2° east-northeast of Lambda (λ) Leporis, the southeast star in this group.

A 15-cm scope at 100× will resolve a tiny disk surrounding a prominent 10th-magnitude central star. IC 418 has relatively strong H-beta emission, so try blinking with an H-beta filter — it will mute the bright central star and enhance the halo.

Although diminutive in size, IC 418 rates high on my list of favourite planetaries because of its very unusual reddish halo in larger scopes. Observing with my 45-cm at 150×, the bright central star is centred in a 10″ halo with a rosy hue at its fringe. When I bump the magnification up to 565×, IC 418 appears annular with a slightly darker centre and brighter rim, but the colour is suppressed. ✦

Contributing editor *Steve Gottlieb* welcomes questions and comments at steve_gottlieb@comcast.net

Aligning Go To Mounts

Get the most out of your computerised scope with these helpful tips.

ROD MOLLISE

When I bought my first telescope that automatically pointed at objects with the push of a button a decade ago, I was embarrassed to admit it to my fellow amateur astronomers. In my mind, that wasn't the way real astronomers worked; we squinted through finder scopes and star-hopped to targets with the aid of star charts.

It didn't take long for me to get over my embarrassment. After 35 years of hunting, I realised I was more interested in looking *at* objects than looking *for* them. Today, the majority of amateur astronomers agree, and most telescopes are sold with Go To-equipped mounts.

You can see plenty of celestial objects with a Go To telescope once it's aligned. The problem is getting it aligned properly. Before your scope can work its magic, its computer has to know where it is and what time it is, and it has to build a model of the sky. With at least a dozen competing Go To systems on the market, I won't give detailed ins and outs of each. All are similar enough that what follows should, with the aid of your scope's manual, get you going.

Before you start pushing the buttons of the scope's hand paddle, let's talk about what doesn't matter in

Whether you're out for a casual look at the sky or setting up for a busy night of astrophotography, aligning your Go To telescope is the most critical step to enjoying a night under the stars. Follow these tips to avoid a frustrating first night out with your equipment. UNLESS OTHERWISE NOTED, ALL PHOTOS ARE COURTESY THE AUTHOR.

Go To alignment. Some new owners obsess over levelling the tripod, going so far as to carry around a bubble level. The truth is, precise levelling doesn't matter much for many Go To mounts. A precisely levelled mount might slew a little closer to initial alignment stars, but final pointing accuracy won't be affected. What's important for good Go To performance is that the telescope's position matches its model of the sky using the alignment stars you centre. "Level by eye" is good enough.

Go To Alignment

The first thing most Go To controllers require is that you input your local time, date and location. Without that, the telescope won't know which alignment stars are above the horizon, or where everything else is in the sky. If your mount has a built-in GPS receiver, it will input all this information for you. If not, then the time shown on your watch, plus the latitude and longitude coordinates from a map, are good enough. In addition to entering time in 12- or 24-hour format, you must set the correct time zone. Most controllers will allow you to enter a time zone (eg. Australian Eastern Standard Time), though some require hours east or west of the Greenwich Meridian. For example, AEST is considered '+10,' or 10 hours east of Greenwich.

Many people run into a problem with time during daylight saving time (DST). If in effect, choose "yes," or "on." If you don't, your scope will point 15° away from its alignment stars. Remember "spring forward, fall (autumn) back" — DST moves the clock an hour forward in the spring and back in the autumn. Not all states use DST, so be sure to check your location if travelling far to observe.

Most Go To telescopes, like this Meade ETX 125PE, require you to begin with the mount in its 'home' position. Usually that requires pointing the telescope due south and levelling the tube.

Hand paddles of three popular Go To mounts by Celestron, Meade and Orion. Although they arrange the command keys differently, they all contain the same basic components: an LCD display, command buttons, directional keys and a numeric keypad.

Next up is location, usually represented in latitude and longitude coordinates. Some Go To users have it easy; their telescopes allow them to select the name of the nearest city. But how close does a city have to be to be accurate? Within about 100 kilometres is fine. If you have to enter latitude and longitude, make sure you punch them in correctly. Enter both figures in degrees and minutes. Some controllers allow you to enter seconds or decimal minutes, but that kind of precision isn't required, so you can just enter 00 at the end. What's important is that you get the proper designations of latitude and longitude correct. For the Southern Hemisphere, enter an 'S' or '-' before the latitude coordinates, and because we're in the Eastern Hemisphere, enter a 'E' or '+' before the longitude coordinates.

After data entry, most controllers will ask if you want to begin alignment. Before you do, make sure the mount's clutches are locked. If you don't, the drive motors will spin, but the telescope won't move anywhere. Also, some mounts require that you place the scope in a home position before alignment. Consult the manual for the particulars, but this often means just pointing the telescope due north.

Before you can begin slewing to your alignment stars, most Go To mounts require you to input important information about your location, including the time, your time zone, daylight saving (if applicable), and your latitude and longitude coordinates. Each Go To system is slightly different.

Now you can start the alignment procedure. Many different alignment systems are in use today, though most involve centreing two or three stars. The difference lies in how those stars are centreed in the telescope's eyepiece. Celestron's SkyAlign system for its alt-azimuth-mounted telescopes, for example, has you point at three bright stars or planets manually with the hand paddle's directional buttons. You don't even have to know the names of the objects. Meade's Easy Align chooses two stars for you, slews the telescope close to them, and then requires you to centre the stars in the eyepiece (also using the hand paddle's directional keys). Both of these systems work well if you centre the correct stars carefully.

Once you begin the alignment process, follow the prompts on the controller to start the telescope slewing to its first alignment star. When the telescope stops, centre the alignment star in the finder and in the main scope eyepiece using the hand paddle's directional keys. How you do that is critically important — it matters more than anything else for a good alignment. The difficulty for beginners is knowing which star to centre. Even if the telescope slews automatically to alignment stars, you'll need some way to identify them, since they will rarely be centred in the finder when the telescope stops.

Most Go To computers list alignment stars by their proper names rather than by the more common Bayer designations. Try to have a star chart handy so you'll quickly know which star your scope is looking for.

Unfortunately, most Go To systems display the proper names of stars rather than their easier-to-remember Bayer designations. Even after almost 50 years as an amateur astronomer, I have a difficult time remembering which star 'Mesarthim' (γ Arietis) is. Keep a simple star chart at hand that labels stars with their proper names. Don't know the sky well enough for that to be much help? You'll usually be okay if you assume the brightest star closest to the centre of the finder's field is your target. Basic knowledge of the stars is a big help, however. Most controllers will often give an 'alignment successful' message once completed, even if you centred the wrong stars. Pointing accuracy will be lousy, though, so you'll quickly realise you need to go through the alignment routine again.

Not only do you have to pick the correct stars, you must centre them precisely. Use a medium power eyepiece, at least 100×, and for best results, one with a crosshair reticle. If you don't have a crosshair reticle eyepiece, defocus the alignment star until it nearly fills the eyepiece field, and you'll be able to centre it easily.

Some beginners get frustrated when their telescope stops a long way from alignment stars. Have patience; often the first alignment star will be 5° or more from the finder's centre. The second should be closer, but even then it might not be visible through the telescope's eyepiece. Just centre the alignment stars and keep on trucking.

If you do everything correctly, you should get an 'align successful' message on the hand paddle display after centring the last star. But when it comes to Go To telescopes, my motto is 'trust but verify.' Before you pack away the crosshair eyepiece, slew the scope to a bright object far from your final alignment star as a test. Is it in the eyepiece at roughly 100×? If not, consult the tips section at the end of this article.

Equatorial Mounts

German equatorial mounts and other equatorial mount designs are popular with amateurs, especially those interested in astrophotography. In most ways the alignment process is the same for them as it is for alt-azimuth mounts. You enter the initial location information the same way, and the same considerations apply. But there is one big difference. Before you can do a Go To alignment, you must do a polar alignment.

Polar alignment is the process of pointing an equatorial mount's right ascension (east-west) axis at the celestial pole, which in the Southern Hemisphere is a little more than 1° from the star Sigma Octantis (or roughly ½° from the bright star Polaris in the Northern Hemisphere). So how close do you have to be pointed to the celestial pole for reliable Go To performance? That depends on the particular brand of your mount.

Some of the newest Go To mounts include GPS or other features that can help automatically align your mount. Celestron's StarSense accessory uses a small camera to photograph a star field and quickly match the image to its internal database to accurately determine where the scope is pointing.

"If you do everything correctly, you should get an 'align successful' message on the hand paddle display."

Poor polar alignment does not affect the Go To accuracy of some equatorial mounts. One night, a fellow club member of mine mistakenly polar aligned his equatorial mount on the wrong star, and yet his Go To pointing was great. Tracking was horrible, of course, since with an equatorial mount it depends on the quality of polar alignment. But some equatorial mounts demand at least a rough alignment for good pointing accuracy. How do you know whether your mount's Go To accuracy is dependent on polar alignment? A tip-off is if the computer's Go To alignment routine requires only one or two alignment stars. Several additional alignment targets are often required to compensate for poor polar alignment.

So what should you do if your mount needs an accurate polar alignment for reliable Go To pointing? If it has a built-in polar-alignment bore scope, use it. If not, there are various easy methods of achieving a close enough polar alignment for good

While there are many excellent features in some of the latest Go To mounts, none will automatically polar align an equatorial mount. German equatorial mounts such as the Celestron VX shown above require you to point the polar axis twoard the South Celestial Pole before continuing its Go To alignment procedures.

Far left: **One thing essential to an enjoyable night of observing with a Go To system is adequate power. Make sure your batteries are fully charged, or that you have access to an AC outlet so your mount doesn't start losing its way as its batteries begin to fail.**

Left: **Be sure to clean any electrical connections regularly; dirt, moisture, or corrosion can often lead to erratic mount behaviour.** *S&T:* SEAN WALKER

Go To performance — you can find instructions online. Some of today's mounts have routines built into their controllers that will allow you to easily polar align by centring stars using the mount's altitude (latitude) and azimuth adjustment knobs.

Once you've completed your Go To alignment, you should have smooth sailing. The telescope should slew to thousands and thousands of objects with a few button presses. Well, it should, anyway. If your mount isn't landing objects in the eyepiece, don't panic — the cause is usually easy to diagnose and fix.

Tips and Troubleshooting

• Alignment star centring

In addition to a star chart with star names, the biggest help I've found for centering alignment stars is a reflex finder such as the reliable Telrad. A correctly orientated, unmagnified view makes it easier for me to be sure I'm pointed at the proper star.

Adding a unit-power reflex finder such as the Rigel QuickFinder shown at left can speed up your Go To alignment routine.

• All alignment stars are not equal

Go To controllers are usually good at choosing alignment stars, but not always. One night my telescope chose a star that was low on the horizon. Go To pointing was way off until I shut the scope down, restarted it, and picked an alignment star higher in the sky. Avoid alignment stars lower than about 20° above the horizon or too near the zenith. If your controller chooses one, reject it and have it pick another (see your mount's manual).

• Adequate power

Computerised mounts draw plenty of power, as I discovered on my first night with a new Go To system. During alignment, the telescope slewed toward the first alignment star, passed it, and kept on going until I pulled the plug. Was my brand-new mount broken? No. The problem was my battery wasn't up to the task. Always use a fully charged 12-volt battery or an AC power supply recommended by the telescope manufacturer. Try to avoid using C- or D-cell batteries if possible.

• Check your connections

A frequent cause of erratic mount behaviour is loose connections. Check the power cable, the hand paddle cable and motor cables. If you keep your mount outside in an observatory, expect to clean connector pins once in a while. A few cotton swabs and some denatured alcohol will usually take care of the problem.

• Computer gremlins

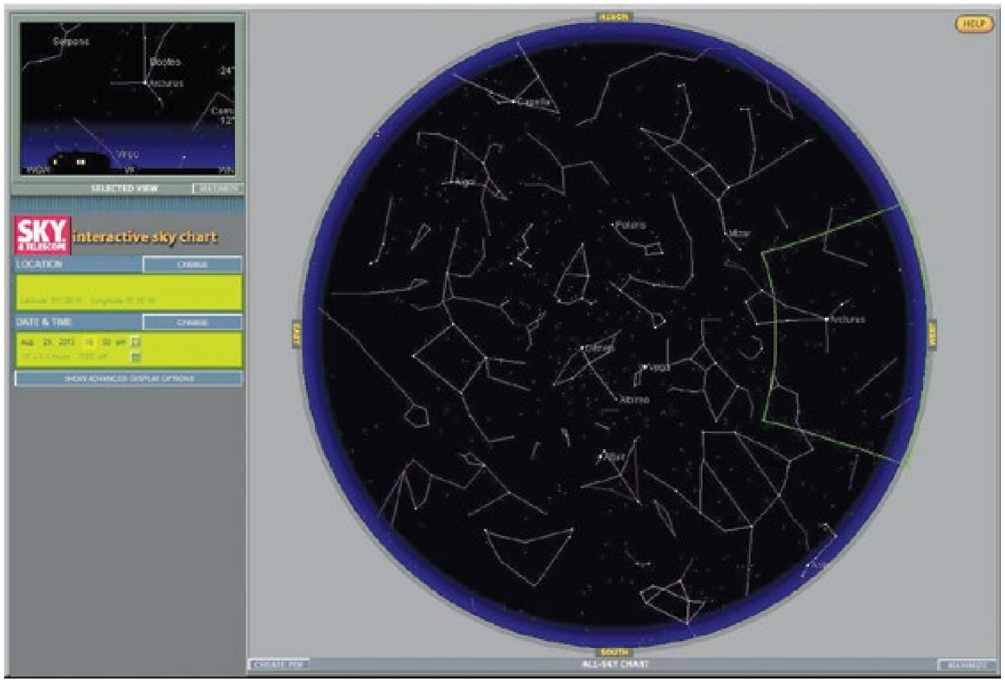
A Go To telescope's hand paddle is a computer, and like all computers it can get confused; its onboard program can become corrupt. If your mount that was formerly well-behaved begins missing Go To targets, try resetting the controller. Most have the menu option to 'reset to factory defaults,' which reinitialises the computer. If you use the option, don't forget to re-enter basic information like time, date and location.

• Precise Go To

Certain objects will cause Go To problems for most mounts no matter how good their alignment, usually ones close to the horizon or zenith. If you're having problems in a particular area of the sky, try the 'precise Go To' option featured in most Go To controllers. When you select an object with precise Go To activated, the scope will first slew to a bright star near the target. Centre this star using the hand paddle directional keys, press Enter, and the scope will continue on to the chosen object.

• Additional sync points

If your mount doesn't have a 'precise Go To' function, or you don't like centering a star before each object, the 'sync' function featured in most controllers can improve pointing accuracy. When you have a star



When setting up your Go To telescope for the first time, it's best to walk through the alignment procedure at home. Use a planisphere to ensure your telescope is slewing in the proper directions before heading out under the stars.

Fork-mounted telescopes only require polar alignment if you intend to photograph the night sky. Consult your telescope's manual for its polar alignment instructions, or use one of the common methods to quickly polar align.
S&T: SEAN WALKER

or other object centred, press the hand paddle's sync button, and the computer will remap the sky, usually making slews more accurate. Unfortunately, if you move the telescope far from the sync point, slews will be off again and you may need to sync on another star.

• Strange behaviour

Go To mounts sometimes do things that seem counter-intuitive but that actually serve an important purpose. If a slew requires crossing the meridian, an imaginary north-south line in the sky, an equatorial mount will often take what seems like the long away around in order to position itself properly for tracking. Similarly, an alt-azimuth mount may go the wrong way to avoid tugging out the hand paddle or motor cables.

• Get comfortable

What's the worst possible place to learn to use a Go To mount? On a dark observing field far from home. Before taking a new mount outdoors, I do a simulated alignment in my living room. A computer planetarium program, Australian Sky & Telescope's Interactive Sky Chart (http://bit.ly/1yaAoh6), or a simple planisphere set for the current date and time will tell me if the scope has pointed in approximately the correct directions of alignment stars. I accept those stars and, with the aid of the planisphere, check to see if the scope points in the area of an object when I initialise a slew.

Learning Go To technology takes a bit of work. New technologies such as Celestron's SkySense or Meade's LightSwitch will automatically align your mount without intervention (though nothing will automatically polar align your mount). These technologies are just coming to market, however, and even when they become common, the tips discussed here will keep you out of Go To trouble.

Once you master your mount, the rewards will be great. A few years ago I set out on a big observing project, observing all of the nearly 2,500 Herschel deep-sky objects. Given the weather where I live, I wouldn't have lived long enough to see them all if I'd had to rely on star-hopping. Go To telescopes enabled me to see every Herschel object in just three years, and I had a ball doing it, spending my time admiring thousands of wonders instead of wondering where they were. ✦

Contributing editor *Rod Mollise* keeps an astronomy blog at uncle-rods.blogspot.com and is author of several books, including *The Urban Astronomer's Guide*.

Imaging Aesthetics

Astrophotography Today

Advanced imagers define the trends of the 21st century.

SEAN WALKER

The excellent sensitivity of modern DSLR cameras has given rise to a new breed of astro imaging: nightscape photography. Pioneer Babak Tafreshi captured this view above São Miguel Island, Portugal, with a modified Canon EOS 7D Mark II DLSR.

There's no question these days that digital media have revolutionised amateur astronomy and, in particular, astrophotography. From the super-sensitivity of CCD and CMOS detectors in our cameras, through inexpensive memory cards, to computer processing suites that completely eliminate the toxic chemicals of the darkroom, never before has the pursuit of astrophotography been so inviting to the amateur.

With all these new tools, imagers have been making leaps and bounds in their ability to reveal new details of the cosmos surrounding us, particularly when looking towards the nearby galactic neighbourhood. So what are the hottest trends in the imaging community? Let's take a look.

Nightscapes: Land and Sky Intertwined

A decade ago, DSLR camera technology was just beginning to reach the level of sensitivity needed to take quality images of the night sky. While some pioneering astro-imagers were beginning to shoot pleasing deep-sky images with DSLR cameras attached to their telescopes, a different breed of astrophotographer was emerging: the

nightscape photographer, one who doesn't use a telescope at all.

Nightscape photographers such as stalwarts Babak Tafreshi (**www.dreamview.net**) and Wally Pacholka (**www.astropics.com**) travel the world to capture breathtaking views of picturesque locations surmounted by the Milky Way above using DSLR cameras and lenses. Their work is meant to connect the casual viewer with the beauty of the sky that surrounds us all. Tafreshi formed the international photography group The World At Night, or TWAN (**www.twanight.org**), which is dedicated to his philosophy that the sky is free for us all to enjoy.

Their craft has improved with the increasing sensitivity of the latest DSLR cameras, particularly ones modified to increase their sensitivity to hydrogen-alpha (Hα) light. The popularity of nightscape photography has led to a burgeoning industry of small tracking mounts specifically designed for DSLR cameras and lenses.

Deep and Wide

Nightscape photographers aren't the only ones shooting wide-angle panoramas of the night sky. A related pursuit is the growing popularity of assembling sprawling mosaics of wide areas in the sky, up to and including deep photographic maps of the entire sky. Trailblazer Nick Risinger (**http://skysurvey.org**) currently holds the mantle for having imaged the entire sky from both hemispheres with a custom rig of FLI cameras attached to Zeiss 85-mm lenses. With this outfit, he's produced a seamless mosaic of the entire sky in visible light down to at least 14th magnitude. You might even have a version of it in your pocket — it's used as the basis for his company Fifth Star Labs' planetarium app *Sky Guide.*

Going much deeper, photographer Rogelio Bernal Andreo (**www.deepskycolors.com**) has made a name by shooting extremely deep panoramas of dusty regions within the Milky Way, often revealing faint nebulosity practically unknown in the amateur community. Andreo combines his mastery of image processing with his love of expansive vistas to produce panoramas of entire constellations, nebulous regions and galaxy groupings using the popular Takahashi FSQ-106EDX astrograph and SBIG STL-11000 CCD cameras.

Other imagers, including former *S&T* senior editor Dennis di Cicco, take the

In this colorful rendition of the "Mexico" portion of NGC 7000, Ken Crawford combines narrowband and broadband images to achieve a unique, heightened color palette.

panoramic-mosaic to another level. By concentrating his efforts on a particular section of the Milky Way throughout an entire season, di Cicco has mapped hydrogen-alpha nebulosity to an extent only seen previously in professional surveys at radio wavelengths.

The planetary photography of Damian Peach may seem like magic to some, but meticulous attention to detail and a mastery of his chosen equipment are what have kept Peach at the forefront of this field of imaging.

Adam Block produces a steady stream of dazzling deep-sky imagery that rivals that of the pros.

Narrowband Nebulae

Moving a bit farther out in the galaxy, narrowband imaging at multiple wavelengths has become a staple of deep-sky imagers, but with a distinct twist. High-end imager Ken Crawford (**www.imagingdeepsky.com**) produces ultra-deep and colourful photos of nebulosity within the Milky Way by imaging through narrowband and colour filters. Crawford blends deep images taken through specialised hydrogen-alpha, sulfur, and oxygen filters, which highlight the chemical make-up of star-forming regions. When combined as red, green, and blue in a colour image, the result is an attractive representative-colour image that helps scientists visualise the distribution of these specific elements in our galaxy.

Narrowband images make colourful nebulae images but have the side effect of giving odd hues to stars. So Crawford also blends in broadband red, green and blue data to recover their natural palette, resulting in mesmerising scenes of nebulosity that benefit from the best of both tri-colour techniques.

Crawford isn't the only practitioner of the narrowband/broadband technique. Don Goldman (**www.astrodonimaging.com**) uses it to produce the deepest amateur photos of extremely faint and obscure planetary nebulae with a remotely controlled telescope here in Australia. Many of Goldman's targets can only be found on professional surveys of the sky, bearing catchy names such as KjPn 8 or LoTr 5.

Imaging for Science
The exceedingly deep

Astrophotography produced by amateurs today has even piqued the interest of professional researchers. One night while browsing online through amateur astrophotos, astronomer David Martínez-Delgado of the Max Planck Institute happened upon an exceedingly deep image of spiral galaxy NGC 5907 captured by R. Jay GaBany (**www.cosmotography.com**) that displayed faint loops surrounding the galaxy. This led to a collaborative partnership between Martínez-Delgado and GaBany, who have since published 13 papers in leading journals on the discovery of tidal star streams and rings in the outer halos of large spiral galaxies.

GaBany primarily uses a 50-cm Ritchey-Chrétien telescope with an Apogee U16M CCD camera to take extremely deep exposures, often lasting dozens of hours recorded over several nights.

There are other amateurs whose imaging straddles the border between the amateur and professional worlds. Readers will be familiar with Adam Block's high-resolution astrophotography (**http://caelumobservatory.com**). Using the 80-cm Schulman telescope at the Mount Lemmon SkyCentre, Block takes advantage of the often superior conditions at this mountaintop facility to record high-resolution images of targets often beyond the reach of amateur equipment. And though he manages the facility, his roots are firmly grounded in the amateur community, from giving public presentations and sky tours, to authoring a monthly column on imaging techniques.

"All these imagers share one trait in common: perseverance. Each continually works to improve his skills."

Pushing the Limits of Resolution

While on the topic of high-resolution astrophotography, when someone says something can't be done, there's a certain kind of person who takes the statement as a challenge. For example, there's Chilean imager Daniel Verschatse (**www.verschatse.cl**). He and Ricardo Serpell used a technique known as 'lucky imaging' to resolve sub-arcsecond features in the famous Homunculus Nebula in Eta Carinae. Lucky imaging is performed by recording many short exposures and combining only the sharpest results to resolve extremely small-scale features in a target. The team used Daniel's 37-cm RCOS Ritchey-Chrétien telescope with an SBIG ST-10XE CCD camera operating at an astounding 13.7-metre focal length!

Deep colour images like this dusty region in Ursa Major dubbed the Angel Nebula are the specialty of Rogelio Bernal Andreo using Takahashi astrographs and an SBIG STL-11000 CCD camera.

Using the same basic technique, New Zealand amateur Rolf Wahl Olsen (**www.rolfolsenastrophotography.com**) achieved a similar feat with decidedly more modest equipment. Olsen resolved the circumstellar disk that surrounds the nearby star Beta Pictoris using a 25-cm Newtonian reflector and a modified webcam. Again, Olsen recorded many short exposures and combined only the sharpest to produce his tour de force.

Planetary Feats

Lucky imaging isn't new. It's a technique pioneered by planetary imagers (such as Australia's Steve Massey, **www.ssmassey.com**) around the turn of this century to overcome the scintillation caused by Earth's atmosphere. Originally developed to take advantage of the video capability of webcams, today's practitioners use high-speed video cameras (borrowed from the manufacturing industry) and large telescopes to record short videos, which are then sorted to identify the sharpest frames to combine. This technique has led to an explosion in the popularity of planetary imaging while simultaneously producing a few true artists known around the world.

Damian Peach (**www.damianpeach.com**) has long been counted as one of the world's best planetary imagers, known for his eye-popping portraits of Jupiter, Saturn and Mars. Peach methodically images the major planets on every clear night, often travelling to remote locations known for steady air. While his cameras change with each improving model, Peach has settled on the Celestron C14 Schmidt-Cassegrain as his primary instrument.

Another world-renowned planetary imager, Australian amateur Anthony Wesley (**www.acquerra.com.au/astro**) also concentrates his efforts on recording the major planets for both science and art. His approach has paid off handsomely: on July 19, 2009, Wesley captured the distinct signature of an impact event on Jupiter, which was confirmed by Hubble observations only days later. Not one to rest on his laurels, Wesley captured an impacting asteroid in the act hardly a year later!

Wesley continues to push the resolution limits of his equipment. In recent months, he has resolved storms on both Uranus and Neptune in infrared light using his home-built 40-cm Newtonian reflector and a Point Grey Research Grasshopper 3 high-speed video camera.

All these imagers share one trait in common: perseverance. Each continually works to improve his skills, and, as a result, each has attained the pinnacle of recognition in his respective area of expertise.

With the impressive quality of commercial optics, cameras and software tools, it isn't that hard to dive into the hobby of imaging, no matter what your level of interest is. And each of these pioneers is easily accessible on the Web and will gladly offer advice to help you climb the learning curve of astrophotography. ✦

Sky & Telescope Imaging Editor **Sean Walker** *still gets excited to see the latest astro-images each day.*

Gary Seronik
Telescope Workshop

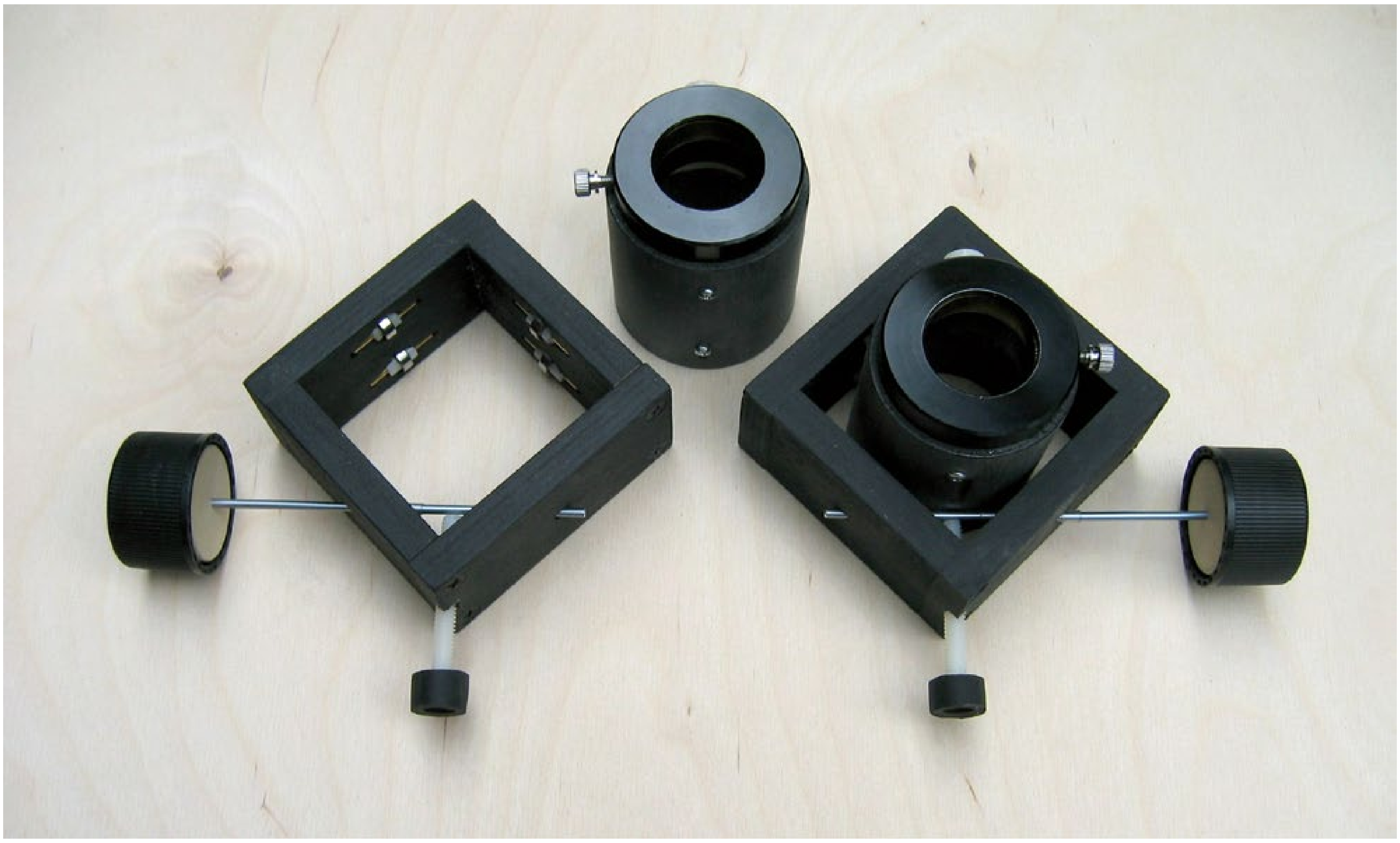
A Simple Homebuilt Focuser

This inexpensive focuser doesn't require a machine shop to build.

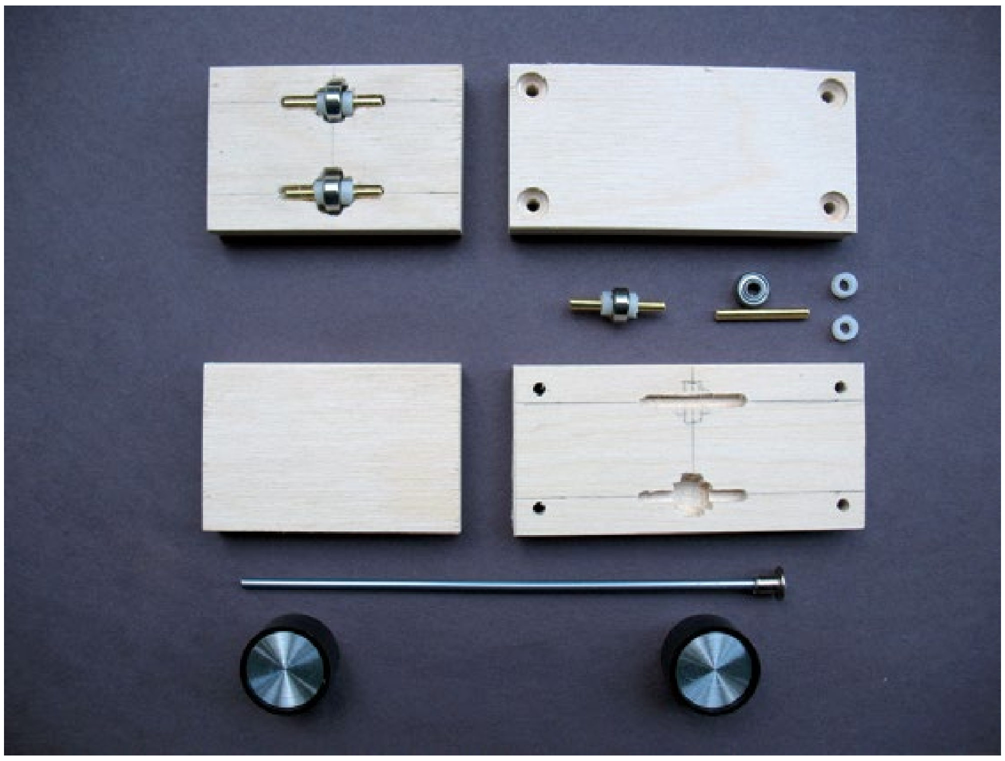
I highlighted Jerry Oltion's 12.5-inch binocular telescope in the February/March issue. That scope has many interesting and novel features, but one I feel merits particular attention is its superb focuser. As Jerry notes, "when you make two of everything, you favour designs that are cheap and simple!" All told, the parts for his focuser add up to less than $10. That's the "cheap" part of the equation, but what about "simple"?

Jerry's focuser is essentially a Crayford design, which means it doesn't utilise the usual rack-and-pinion mechanism found in many commercial units. In a Crayford focuser, a rotating shaft presses against the focusing barrel, which moves back and forth against a set of bearings. In Jerry's version, the mechanism is contained in a 92-mm-square, 45-mm-deep box made from 12.5-mm plywood. As the picture on the facing page shows, the four bearing assemblies each consist of a 2.5-cm long piece of 3-mm brass rod, a small bearing, and two nylon spacers. "Any small bearings will do," Jerry says. "Model helicopters and model cars often have bearings the right size." Add a 2.5-mm-diameter knitting needle for the focuser shaft, a length of 5-cm inside-diameter PVC tubing, a couple of knobs and a nylon screw, and you have the entire parts list.

Jerry Oltion's binocular telescope requires two of just about everything, which pushed him to design components that are both inexpensive and easy to make. His Crayford-type focuser is one of the scope's most innovative features. JERRY OLTION



The focuser partly disassembled. The nylon screw at the bottom of the housing is used to increase friction between the focuser shaft (a knitting needle) and the draw tube (a length of 5-cm inside-diameter PVC tubing). JERRY OLTION



The main elements of Oltion's focuser are shown here; the only component missing is the PVC draw tube. All the parts can be sourced at a well-stocked hobby shop or hardware store.
JERRY OLTION

The first step in construction is to hollow out cavities in two of the wood body panels to accommodate the bearing assemblies. A router works well for this task, or you can improvise as Jerry did. "I used a drill bit that I snapped off near the bottom as a makeshift router bit, and put that in my drill press," he explained. "I lowered the bit and pushed the wood around to carve out the bearing cavity and the groove for the axle."

Accurately positioning the bearings is the only crucial part of construction. You must ensure that each bearing assembly is recessed by an equal amount. As Jerry says, "for the drawtube to sit square, you have to make sure all the bearings are the same height." And if you're going to err, do it on the side of going too deep; you can fine-tune the bearing axle height later using shims.

Once the box is assembled, the next step is to drill a hole for the knitting-needle drive shaft. "It's better to make the shaft too tight against the drawtube than too loose, because you can always widen the hole outward if you need to," Jerry advises. Ideally, when the focuser is assembled, the shaft is nice and snug against the draw tube, but not so tight that it bends. The nylon tension-adjustment screw on the bottom of the housing allows you to fine-tune the friction according to your needs.

Finally, it's a good idea to include a pair of safety stops at each end of the focuser draw tube to prevent it from falling into your scope, or extending out too far and crashing to the ground (taking an expensive eyepiece along with it). "I used small pan-head screws spaced to hit the knitting needle before the end of the draw tube travels too far past the bearings," Jerry says.

Of course, a focuser that's inexpensive and simple to make isn't worth much if it doesn't work well. The beauty of this design is that good results are practically guaranteed if you take the time to position the bearings with care. "In use, the focusing action is a little finer than most single-speed units, and a little coarser than the slow speed of most two-speed focusers," Jerry reports. "Overall, it's smooth, solid, and makes finding the focus sweet spot easy. After a while you'll even forget it's homemade."

Readers wishing to learn more about Jerry's Crayford focuser can visit his web site at www.sff.net/people/j.oltion/boxycrayfords.htm. ✦

Contributing Editor *Gary Seronik* is an experienced telescope maker and binocular observer. You can contact him via his website, *www.garyseronik.com*.

TINY AUTOGUIDER Starlight Xpress announces the Lodestar X2 Autoguider. This tiny imaging and autoguiding camera features a low-noise Sony ICX829ALA EXview HAD CCD II detector with a 752 × 580 array of 8.2 × 8.4-micron pixels. Weighing 85 grams, this ultra-light camera is housed in a convenient 1¼-inch-diameter aluminum body that fits into any standard 1¼-inch focuser. The detector end also includes C-mount threads for additional interface requirements. The camera connects to your computer via a USB 2.0 Mini interface (which also provides power) and downloads a full-resolution image in 0.2 seconds. The autoguider also has an RJ12 connector port to directly connect to your telescope mount.

Starlight Xpress
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EXTREME EYEPIECES Meade Instruments unveils its new Series 5000 Mega Wide Angle eyepieces. These wide-field oculars feature an expansive 100° apparent field of view with comfortable eye-relief of 13 to 20 millimeters that can accommodate observers wearing eyeglasses. Both of the 5- and 10-mm models fit 1¼-inch focusers, while the 15- and 21-mm versions are 2-inch format only. Each Mega Wide Angle eyepiece incorporates blackened lens edges to enhance contrast, and their parfocal design requires little or no focus change when switching between eyepieces within the series.

Meade Instruments
www.meade.com
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MULTI-MOUNT Sky-Watcher has introduced its AZ-EQ5 GT Mount. This multi-purpose Go To telescope mount is equally useful as a German equatorial mount, or operating in alt-azimuth mode. The AZ-EQ5 GT features hybrid stepper motor drives on both axes for smooth slewing at up to 4.2° per second. Capable of supporting up to 15 kilograms of gear excluding counterweights, the mount accepts the standard ST-4 style autoguider input for astrophotography, and also has a DSLR shutter control port. Its SynScan Go To controller contains a database of more than 42,000 objects, including all the Messier, NGC, IC and Caldwell catalogues, and much more. The AZ-EQ5 GT also provides two 3.5-kg counter-weights, an adjustable tripod with 4.5-cm stainless steel legs, and a DC power adapter.

Available from local Sky-Watcher dealers

GO LOCAL

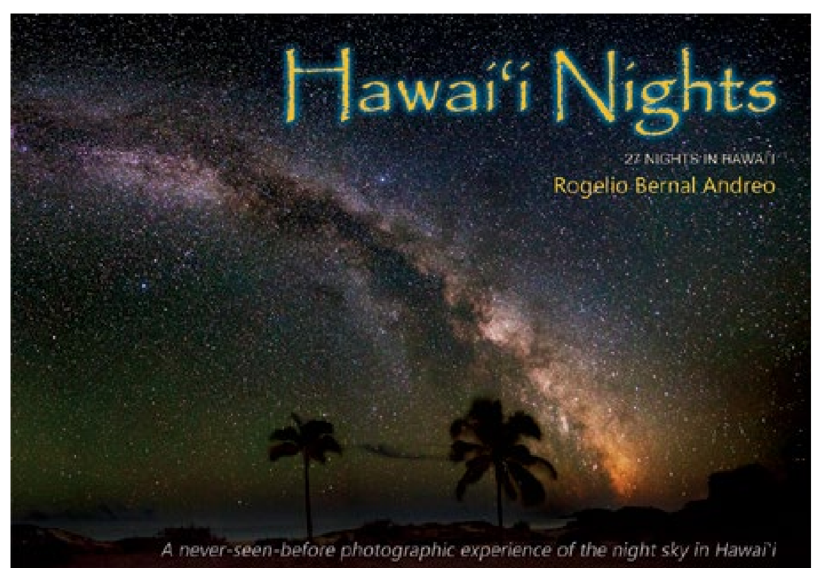
We strongly recommend that you seek out your local dealer or distributor for products listed on these pages. Local companies will provide you with a local warranty, lots of advice and valuable after-sales service.

🡐 SPHINX TWO Vixen's New Sphinx SX2 Equatorial Mount is the latest entry in its line of award-winning telescope mounts. This German Equatorial Go To mount features 180-tooth aluminium alloy gears and brass worms driven by precision stepper motors in both right-ascension and declination axes. The Sphinx SX2 is usable between 0° and 70° latitude and includes a retractable stainless steel counterweight shaft. Both RA and dec motors are housed within the declination axis, functioning as a built-in counterweight. The mount includes manual slow-motion knobs on both axes, and a 10.5-kg counterweight. The SX2 also comes with Vixen's new Star Book One Go To hand controller, enabling you to slew at up to 999× sidereal rate to thousands of targets. The mount accepts the standard ST-4-style autoguider input for astrophotography and also includes a cigarette lighter DC power adapter.

Available in Australia from Astro Shop
astroshop.com.au

🡓 DIGITAL CATALOG Astro Devices introduces the Nexus DSC, a digital setting circle computer for your telescope. The Nexus DSC unit features a database of more than 60,000 objects and can be expanded to up to 1.7 million objects via an optional Micro SD memory card. The unit displays information on a red OLED display that functions at very low temperatures, powered by an internal rechargeable lithium battery. Nexus DSC automatically detects and inputs the precise time and location with its built-in GPS receiver. The DSC can connect with most tablets, smartphones, and computers through an RS232 cable or via an optional Wi-Fi interface. The unit is compatible with ServoCAT and SiTech motor controllers and most planetarium software programs. Telescope encoders are sold separately.

Astro Devices
www.astrodevices.com



ISLAND IMAGING PREMIER astrophotographer Rogelio Bernal Andreo has published his first book Hawai'i Nights, documenting his nearly month-long photographic adventure visiting the islands. This landscape-format book measures 21 × 30 centimetres and is divided into informal chapters based on the nights he spent snapping breathtaking photos of the night sky on each of the main islands. The book features more than 70 photos of famous Hawai'ian locations seen under the stars, many as two-page spreads. Hawai'i Nights is available as a digital download for US$24, in paperback for US$49, and in hardcover for US$65. 115 pages, ISBN 978-0-9906763-2-4.

Deep Sky Colors
www.deepskycolors.com/hawaii-nights.html

Astrophotos from our readers

CARINA NEBULA

Theo Pistorius

The Carina Nebula is four times larger than the more famous Orion Nebula. Theo used a Canon 350D camera and Canon EF-S 55-250mm lens (with UV filter) at 250mm, f/5.6 at ISO 800 with an iOptron SkyTracker mounted on a Meade tripod.

JUST PASSING BY

Jamie Cooper

Comet C2014 Q2 (Lovejoy) is seen silently sliding past the Pleiades on January 15, 2015. Jamie took this shot from Lanzarote in the Canary Islands. Camera was a Canon 6D with 100mm f/2.8 lens at f/4, and seven 60-second exposures at ISO 4000.

▲ **LOOKING FOR LOVEJOY**

Peter Sayers

This is what it's all about – under the stars, waiting for the clouds to clear. Peter Sayers, Leigh Bryan, John Henry and Brett Hallet were at Brett's observatory in Latrobe, Tasmania, looking for Comet Lovejoy. This was a 30-second exposure with a Canon 6D.

▶ **MILKY WAY**

Andrew Jackling

The Large Magellanic Cloud makes an appearance with the Milky Way in this picture taken from Lake Eildon in Victoria. Andrew used a Canon 5D Mark II with a Samyang 14mm lens, for 30 seconds at f/2.8.

STAR FIELDS
Will Vrbasso
Northern astronomers, eat your hearts out! Will's image is of the amazing Milky Way region of Crux (lying on its left-hand side at the bottom of the image) and Carina, taken under the dark skies of Kalgoorlie, WA. For this mosaic of 24 images he used a Canon EOS 6D plus Canon 200mm f/2.8 lens on an unguided mount.

HOW TO SUBMIT YOUR IMAGES

Images should be sent electronically. Please first send a low-res JPG version to contributions@skyandtelescope.com.au, and we'll get back to you with information on how to send your hi-res versions if selected. Please provide full details of all images, eg. date and time taken; telescope and/or lens used; mount; imaging equipment type and model; film (if used); filter (if used); exposure or integration time; and any software processing employed. Readers who have a contributed image published in *Australian Sky & Telescope* will receive a 3-issue subscription to the magazine.

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NASA

Dawn arrives at Ceres

NASA's intrepid Dawn spacecraft enters into orbit around the largest body in the main asteroid belt, the dwarf planet Ceres.

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What famous observatory has no lens and no mirror? It's the WorldWide Telescope, an interactive web browser for the sky. And best of all, it's free.

Astronomy apps

Astronomy apps crowd the Apple and Android app stores. We asked our experts to recommend some of the best.

NASA's flying observatory

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In Praise of Serious Dark

A trip to a dark sky site opens unimaginable new vistas overhead.

As observers, we all know that a dark-sky site vastly improves the view of deep-sky objects. But how many of us really know what this is like when taken to its ultimate? Likely only a few percent of us have enjoyed observing from a seriously dark location: black sky, not a spark of artificial light, trees visible only as silhouettes against airglow. Until you first experience it, you can't properly envision it; too much emerges, with increasing rapidity, as you progress into deep darkness.

"Stars are large and close, and those barely seen back home now so clutter the sky that familiar constellations are lost in the riot."

© CANSTOCK PHOTOS / RENOMARK

I learn this firsthand on a trip to a national park. I want to turn my 25x100 astronomical binoculars onto the Milky Way from a place with serious darkness.

It's low season, and the six of us are alone in the park. There are no artificial lights or other people, as far as we know, for a good 50 kilometres, and the nearest tiny towns are 70 and 140 kilometres away. When I step out of the van, the full, encompassing darkness is startling. The depth of darkness of foreground and landscape is utterly foreign to a city dweller — profound and assertive.

Then I look up. The Milky Way glows like night clouds illuminated by suburbs. Stars are large and close, and those barely seen back home now so clutter the sky that familiar constellations are lost in the riot.

I set up the binoculars, sit down at the eyepieces, and venture a look, star chart in hand. But after starting at Sagittarius and prowling though the Scutum star cloud, I put the chart aside and just slowly wander gawking through the glowing glories of the galactic bulge.

The big binoculars show endless sights as I've never seen them before. Celestial gems appear in wild profusion: open clusters, globulars, emission nebulae, and clouds of pinpoints as well as mists of uncountable unresolved stars. Omega, Eagle, Trifid, Lagoon, Wild Duck, Ptolemy's, other Ms too numerous to count — practically every field is crowded with sights more stunning than those in the last.

The experience recalls a foundational event for my love of binocular astronomy. It was that magical night, at age 13, when I lay under an impossibly dark and starry sky on a camping trip. I gazed through binoculars at the Milky Way straight overhead, lost in wonder at the multitudes of stars and objects whose mysterious and enchanting symbols I had pored over in my *Norton's Star Atlas*. That long ago sky, like the sky over me now, is immortal and known only to us pilgrims.

Hours later, after a long cruise through sky, I've finally had my fill. I'm tired, and Andromeda and Triangulum won't be up before dawn. I stumble into bed, trying in vain to describe my elation to my sleepy wife. In the end, I settle on the simple wish that every observer who possibly can will, even if just once, make the pilgrimage to Serious Dark. ✦

***Howard L. Ritter, Jr.*, a haematologist, has been an enthusiastic advocate of binocular astronomy ever since that night when he was 13. His bucket list includes a longer visit to that same national park. And bigger binoculars.**